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# PROCEEDINGS: SIXTH ANNUAL WORKSHOP ON METEOROLOGICAL AND ENVIRONMENTAL INPUTS TO AVIATION SYSTEMS

OCTOBER 26-OCTOBER 28, 1982

UNIVERSITY OF TENNESSEE SPACE INSTITUTE



EDITORS: WALTER FROST  
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U.S. Department  
of Transportation

Federal Aviation  
Administration



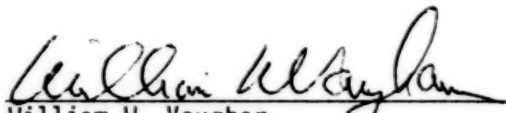
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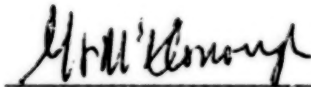
APPROVAL

PROCEEDINGS: SIXTH ANNUAL WORKSHOP ON METEOROLOGICAL  
AND ENVIRONMENTAL INPUTS TO AVIATION SYSTEMS

Edited by Walter Frost and Dennis W. Camp

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

  
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16. ABSTRACT The proceedings of a workshop on meteorological and environmental inputs to aviation systems held at The University of Tennessee Space Institute, Tullahoma, Tennessee, October 26 - 28, 1982, are reported. The workshop, jointly sponsored by NASA, NOAA, and FAA, brought together many disciplines of the aviation communities in round table discussions. The major objectives of the workshop are to satisfy such needs of the sponsoring agencies as the expansion of our understanding and knowledge of the interaction of the atmosphere with aviation systems, the better definition and implementation of services to operators, and the collection and interpretation of data for establishing operational criteria relating the total meteorological inputs from the atmospheric sciences to the needs of aviation communities. The unique aspects of the workshop were the diversity of the participants and the achievement of communication across the interface of the boundaries between pilots, meteorologists, training personnel, accident investigators, traffic controllers, flight operation personnel from military, civil, general aviation, and commercial interests alike. Representatives were in attendance from government, airlines, private agencies, aircraft manufacturers, Department of Defense, industries, research institutes, and universities.					
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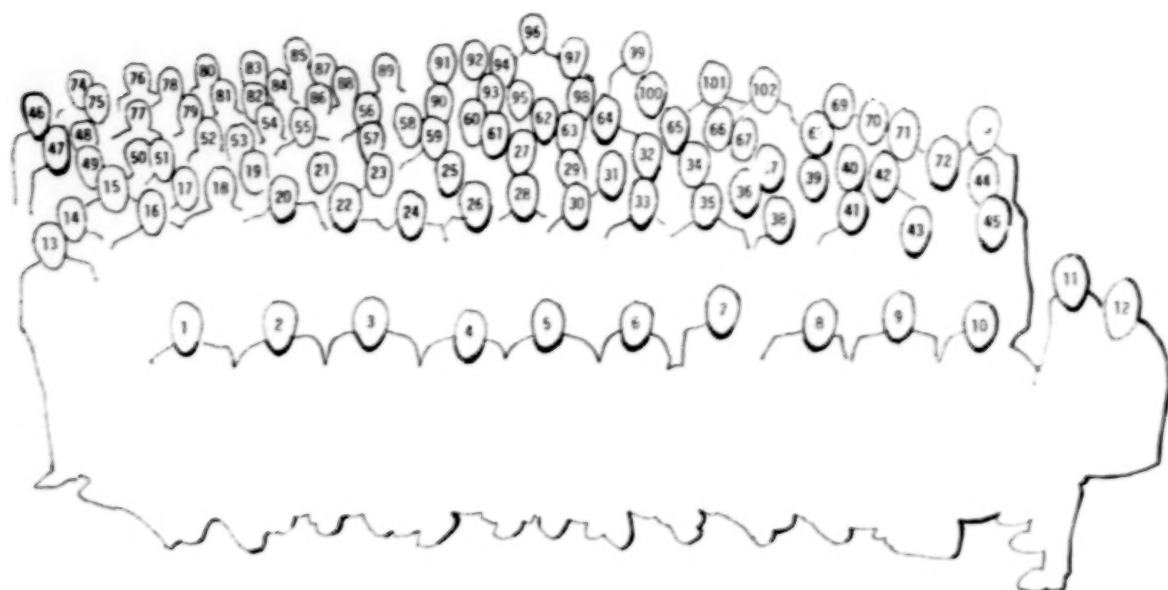
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**WORKSHOP PARTICIPANTS**



## LIST OF PARTICIPANTS

- |                          |                        |                       |
|--------------------------|------------------------|-----------------------|
| 1. Bob Wedan             | 41. Kao-Huah Huang     | 81. Jim Sullivan      |
| 2. Col. Paul Try         | 42. Fred Hrchreiter    | 82. Steve Cohen       |
| 3. Charlie Sprinkle      | 43. JoAnn Painter      | 83. Norm Crabill      |
| 4. Jack Enders           | 44. Col. Cam Tidwell   | 84. John Prodan       |
| 5. Roger Winblade        | 45. Steve Henderson    | 85. Maj. Gary DuBro   |
| 6. Peggy Evanich         | 46. Jack Bliss         | 86. Byron Phillips    |
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| 10. Linda Herselman      | 50. Frenando Caracena  | 90. Jean Lee          |
| 11. Paul Trotter         | 51. Russ Lawton        | 91. John McCarthy     |
| 12. Jim Purdom           | 52. Col. John Fox      | 92. John Blasic       |
| 13. Jim Banks            | 53. Keith Mordoff      | 93. Bob Sleeper       |
| 14. Dave Holmes          | 54. Neil Allen         | 94. Dale Istwan       |
| 15. Jack Hinkelman       | 55. Tom VonderHaar     | 95. Bill Pickron      |
| 16. Maj. Ed Jenkins      | 56. Alan Woodfield     | 96. Jules Bernard     |
| 17. Andy Yates           | 57. Norman Buss        | 97. Porter Perkins    |
| 18. Lt. Col. Ron Brown   | 58. Wayne Sand         | 98. Bob Giordano      |
| 19. August Auer          | 59. Jim Luers          | 99. Harry Chambers    |
| 20. Tom Greer            | 60. Robert Bonner      | 100. Frank Van Demark |
| 21. John Klehr           | 61. Tommy Trimble      | 101. Art Hansen       |
| 22. Terrell Wilson       | 62. Wen Painter        | 102. Ossi Korhonen    |
| 23. Demos Kyrakis        | 63. Robert Miller      |                       |
| 24. Ted Mallory          | 64. August Stasio      |                       |
| 25. Frederick Carr       | 65. Bill Melvin        |                       |
| 26. Vincent Oliver       | 66. Richard Cale       |                       |
| 27. Fred Ostby           | 67. Mark Dietersberger |                       |
| 28. Warren Campbell      | 68. Tom Genz           |                       |
| 29. Sheri Sankey         | 69. Don Cornwall       |                       |
| 30. Col. Farid Chede     | 70. Keith Balcom       |                       |
| 31. Russ Peterman        | 71. Leo Boyd           |                       |
| 32. David Sankey         | 72. Ken Glover         |                       |
| 33. Hugh Christian       | 73. Keith Hill         |                       |
| 34. George Fichtl        | 74. Herb Brody         |                       |
| 35. John Theon           | 75. Dave Winer         |                       |
| 36. Vernon Keller        | 76. Jim McLean         |                       |
| 37. Roland Bowles        | 77. Jim Evans          |                       |
| 38. Cathy Kessinger      | 78. C. L. Chandler     |                       |
| 39. Jan Tissot van Patot | 79. Geoff Molloy       |                       |
| 40. Joe Sower            | 80. Bill Vaughan       |                       |

(Not pictured)

Sepp Froeschl  
Bob Serafin  
Bob Turner  
Roger Weldon

# **SECTION I EXECUTIVE SUMMARY**



## **MEMBERS OF THE ORGANIZATION COMMITTEE**

( FROM LEFT TO RIGHT )

Walter Frost, UTSI  
Dennis W. Camp, NASA/MSFC  
Peggy Evanich, NASA HDQ.  
Frank Coons, FAA, Retired  
Charles H. Sprinkle, NOAA/NWS



# EXECUTIVE SUMMARY: Sixth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems

October 26 - 28, 1982  
Tullahoma, Tennessee

Dennis W. Camp, Walter Frost  
Frank Coons, Peggy L. Evanich, Charles H. Sprinkle

## INTRODUCTION

Six annual workshops on the subject of meteorological and environmental inputs to aviation systems have been sponsored by the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), and the Federal Aviation Administration (FAA). These workshops have been hosted by the University of Tennessee Space Institute (UTSI) at Tullahoma, Tennessee. From the workshops, the sponsoring agencies have a twofold purpose: first, to bring together in interactive discussions the various disciplines of the aeronautical community with meteorologists and atmospheric scientists. A list of some of these disciplines would include, for example: pilots, airline personnel, general aviation persons, aircraft manufacturers, researchers, weather forecasters, avionics personnel, aeronautical educators, accident investigators, aircraft designers, regulators, etc., from both the civil and military aeronautical communities. These interactive discussions are considered to be one of the main features of the workshop. From these discussions, an effort is made to establish and identify the weather needs of the community and how these needs might be satisfied. An indication of how well this purpose was met, relative to the various disciplines, can be obtained by considering Table 1. This table lists the organizations of the 125 attendees at the sixth workshop. These attendees, representing 54 organizations, were assigned to the committees as listed in Table 2.

The second part of the purpose is to use the established and identified needs to develop recommendations that serve as a basis to structure the relevant programs of the sponsoring agencies in an effort to enhance aviation safety and efficiency. Results, which are an indication of how well the purpose of the workshops has been accomplished, are given in the published proceedings (Camp and Frost 1977, 1979, 1981; Frost and Camp 1978, 1980) for each of the workshops. With an exception of the first workshop, summary reports have also been published in the Bulletin of the American Meteorological Society (Frost, et. al. 1979a; Camp, et. al. 1980a, 1980b, and 1982). Presentations at various meetings and conferences have been given relative to the workshops (Frost, et. al. 1979b; Frost and Camp 1982; and Camp, et. al. 1981). Due to the extensive coverage of the earlier workshops, as noted, this paper will

summarize only the most recent workshop, namely the sixth.

## WORKSHOP OBJECTIVES AND THEME

The workshop objectives are to satisfy the needs of the sponsoring agencies relative to such factors as knowledge of the interaction of the atmosphere with aircraft and airport operations, better definition and implementation of meteorological services to operators, and the collection and interpretation of data for establishing operational criteria relating the total meteorological inputs from the atmospheric sciences to the operational and educational needs of the aeronautical community. While maintaining these objectives, each workshop has had an individual theme

The first workshop, which was conducted in 1977, provided a forum for the various disciplines of the aviation community to express their individual and collective views on weather problems relative to aeronautical systems. The second focused on a detailed examination of the most severe weather problems identified at the first workshop, with a view toward seeking consensus on appropriate public and private sector actions needed to solve the problems. At the third workshop, an effort was made to explore the training and educational requirements which were identified at the first two workshops. By the time the third workshop had been conducted, it was apparent that an evolutionary process was more or less established relative to the workshop themes. That is, the results of the previous workshops would indicate what the theme of the next workshop should be. The theme which evolved for the fourth workshop was "Measuring Weather for Aviation Safety in the 1980's." For the fifth workshop, the theme was "Impact of Meteorology on Future Aviation Efficiency, Operations, Design and Safety." The last, sixth, workshop had as its theme "Satellites and Other Aviation Weather Facilities."

## WORKSHOP FEATURES

In order to establish a common base for the interactive discussions by the committee members and to set the tempo for the working sessions, the workshop began with a panel discussion. The panel (Table 3) was made up of members of the sponsoring agencies as well as other agencies who provide meteorological services. Each panel member reviewed their



TABLE 1  
ATTENDEE REPRESENTATION

FEDERAL GOVERNMENT SECTOR (49)

Federal Aviation Administration  
National Aeronautics & Space Administration  
National Oceanic & Atmospheric Administration  
National Transportation Safety Board  
Transportation System Center  
U. S. Air Force  
U. S. Army  
U. S. Navy

PRIVATE SECTOR (56)

Airlines (10)

Delta Airlines  
Federal Express Corporation  
Flying Tiger Line  
Northwest Airlines  
Qantas Airways, Ltd.  
Republic Airlines  
United Airlines  
US Air

Associations (9)

Air Traffic Control Association (ATCA)  
Aircraft Owners and Pilots Association (AOPA)  
Air Line Pilots Association (ALPA)  
Flight Safety Foundation (FSF)

Foreign (6)

Atmospheric Environment Service of Canada  
Brazilian Air Force  
Finnish Meteorological Institute  
Qantas Airways, Ltd.  
Royal Aircraft Establishment

Industry (17)

AnaTex Corp.  
Av-Con Corp.  
Boeing Co.  
Enterprise Electronics  
Environmental Research Application, Inc.  
Environmental Satellite Data, Inc.  
Frank E. van de Mark, Inc.  
FWG Associates, Inc.  
JoWen Aviation  
Martin Marietta Aerospace Co.  
MITRE Corp.  
Radian Corp.  
R & D Associates  
Salt Lake City Airport Authority  
Singer Corp.  
Tennessee Eastman Co.

News Media (2)

Aviation Week & Space Technology  
TV/The Weather Channel

Private Consultants (3)

University and Research Organizations (16)

Colorado State University  
Harvey Mudd College  
MIT Lincoln Laboratory  
National Center for Atmospheric Research  
University of Dayton Research Institute  
University of Oklahoma  
University of Tennessee Space Institute  
University of Wyoming

agency's goals and ongoing research relative to the impact of meteorology on the development and use of facilities for aviation safety and operations. Emphasis was on satellite facilities, communication facilities, forecasting facilities, training/simulation facilities, and operations/airport facilities. Discussions with users in attendance was moderated following the panel presentations.

Round table working sessions took place following the panel discussions. The product of the working sessions was a position paper from each of the committees relative to their assigned topic areas. The topic areas were used to identify the committees. These topic areas or committee titles (Table 2) for the fixed committees were satellite facilities, communication facilities, forecasting facilities, training/simulation facilities, and operations/airport facilities. Five additional floating (rotating) committees entitled (1) passenger airlines,

(2) cargo airlines, (3) general aviation, (4) corporate aviation, and (5) military aviation were organized.

Committee members were invited such that the distribution of expertise on each committee would encompass not only the topic area of the committee but also the meteorological areas of winds, wind shear, and turbulence; icing and frost; atmospheric electricity and lightning; fog, visibility, and ceiling; and ozone and other meteorological parameters (e.g., precipitation and temperature) as well. Working sessions, where each of the five floating committees met individually with each of the fixed committees, were conducted.

During the course of the workshop, time was allocated for a number of participants to make either an invited or an impromptu presentation. Titles and authors of these presentations, which also served to stimulate the discussions of the

TABLE 2  
WORKSHOP COMMITTEES  
AND RESPECTIVE COMMITTEE CHAIRMEN

<u>FIXED COMMITTEES</u>	<u>FLOATING COMMITTEES</u>
<u>Satellite Facilities</u>	<u>Passenger Airlines</u>
James F. W. Purdom Chief, NESS RAMM Branch NOAA/National Environmental Satellite Service	James F. Sullivan Weather Watch Manager US Air
<u>Communications Facilities</u>	<u>Cargo Airlines</u>
Frank E. Van Demark President Frank E. van de Mark, Inc.	Robert L. Giordano Manager of Flight Safety Federal Express Corp.
<u>Forecasting Facilities</u>	<u>General Aviation</u>
Fred Ostby Director, National Severe Storms Forecast Center, NOAA/NWS	Russell Lawton Assistant Vice-President AOPA Air Safety Foundation
<u>Training/Simulation Facilities</u>	<u>Corporate Aviation</u>
Ted Mallory Regional Director Flight Standards & Training Republic Airlines	C. Leo Boyd Chief Pilot Tennessee Eastman Co.
<u>Operations/Airport Facilities</u>	<u>Military Aviation</u>
Thomas E. Greer Deputy Director of Airports Salt Lake City Airport Authority	Lt. Col. John D. Fox USAF Airlift Center

various committees, are listed in Table 4. In addition to these presentations, John Theon, of the Atmospheric Dynamics and Radiation Branch, NASA Headquarters, gave an excellent banquet speech on "Applications of the Space Perspective to Aviation." Another excellent speech was made by John McCarthy, National Center for Atmospheric Research, on the Joint Airport Weather Studies (JAWS) Project.

The workshop concluded with a plenary session consisting mainly of the working session chairmen presenting an overview of their committee discussions and an outline of the forthcoming position papers, which are published in these workshop proceedings. General comments, questions, and recommendations from the entire group were called for during the final session. A brief synopsis of the session chairmen's comments is given in the next section, while the full-length presentation is given in the section entitled "Committee Reports."

## WORKSHOP COMMENTS AND RECOMMENDATIONS

The participants of this workshop, like the previous workshops, had numerous comments and recommendations. Some of the many recommendations are listed in Tables 5 - 10. In these tables, it can be noted that similar recommendations

seem to recur from workshop to workshop. This is to be expected, for two obvious reasons. First, these recurring recommendations are relative to the weather factors having what could be termed the most detrimental effect on aviation operations, e.g., wind shear, icing, severe weather, etc. The second reason, being equally obvious, is that the problem caused by the particular phenomena has not been satisfactorily solved. It is quite possible that some of the weather problems for aviation may never be completely solved. It seems as though research is needed from time to time to reduce or solve a particular problem, then a new development comes along which, in turn, brings back some old weather problem.

Table 5 reviews some of the comments and recommendations concerning equipment and instrumentation. Those listed were chosen to illustrate the point that efforts are needed relative to research, training (simulators), communication, observations, forecasting, etc. This table of recommendations also illustrates the point that satellite information is considered of major importance to the aviation community (note second recommendation). This one also illustrates a comment by John Theon in his banquet speech, namely:

TABLE 3  
PANEL MEMBERS' PRESENTATIONS

Panel Moderator:	
John H. Enders President Flight Safety Foundation, Inc. Arlington, Virginia	
<u>SPEAKERS</u>	<u>TOPIC TITLES</u>
Charles H. Sprinkle National Weather Service National Oceanic & Atmospheric Administration Washington, DC	Aviation Weather Services
Roger L. Winblade Office of Aeronautics & Space Technology National Aeronautics & Space Administration Washington, DC	NASA's Aviation Safety-Meteorology Research Programs
Col. Paul D. Try Office of Under Secretary of Defense for Research and Engineering Pentagon Washington, DC	Department of Defense Meteorological and Environmental Inputs to Aviation Systems
Robert W. Wedan Office of Associate Administrator for Development of Logistics Federal Aviation Administration Washington, DC	Federal Aviation Administration Weather Programs to Improve Aviation Safety

TABLE 4  
INVITED AND IMPROMPTU PRESENTATIONS

<u>TOPIC TITLES</u>	<u>AUTHORS</u>
Current Status of Visibility Sensors for Aviation	David C. Burnham U. S. Department of Transportation
A cursory Glance at Results from NASA's B-57B Gust Gradient Program	Warren Campbell NASA/Marshall Space Flight Center
Weather Concept From Cockpit	Col. Farid Cezar Chede Brazilian Air Force
Lightning Strike Experience in the NASA F-106B Storm Hazards Program	Norman L. Crabill NASA/Langley Research Center
GEM: Statistical Weather Forecasting Procedure	Robert G. Miller National Weather Service
The NASA Aircraft Icing Research Program	Robert J. Shaw NASA/Lewis Research Center
Existing Wind Observation Network	David E. Winer Federal Aviation Administration
Marked Surface Inversions and Wind Shear - A Safety Risk for Departing Aircraft	Ossi Korhonen Finnish Meteorological Institute
The PROFS FAA/CWSU Support Evaluation Project	John W. Hinkel, Jr. National Oceanic and Atmospheric Administration

"The future of satellite applications to aviation looks very bright. Satellite instrumentation will contribute to better wind measurements, improved aircraft/ship routing, improved short-range and medium-range weather forecasting and better communications, including search and rescue capabilities."

Table 6 is concerned with comments and recommendations relative to forecasts and informational updates. The main point to be noted from this table is the concern for better and more timely weather information and how it can be obtained. It is interesting to note that the workshop participants, especially for items in this table, readily identified who they thought should accomplish the recommended effort.

TABLE 5

COMMENTS AND RECOMMENDATIONS CONCERNING  
EQUIPMENT AND INSTRUMENTATION

- Install automated weather observation equipment in those areas which lack real-time weather information.
- There is a need for a more complete and accurate worldwide data base for aviation meteorological parameters such as ceilings, visibilities, winds, and temperature. It is possible that satellites could be used to meet this need. The AFGL and Air Force Global Weather Central should continue development of weather satellite applications in conjunction with NOAA agencies.
- Since military pilots probably have less experience flying in severe weather, it is vitally important that they have current state-of-the-art flight simulators, which include weather effects to aircraft. Thus, the Air Force System Command, Aeronautical Space Division, should continue to develop state-of-the-art simulators for military use.
- All remote airports with lighted, paved runways with IFR approaches need automated weather-reporting equipment with airborne pilot access to this information.
- An effort is needed to develop a communications system, possibly a Data Link, to take advantage of real-time weather and wind information constantly available from an en route aircraft.

TABLE 6

COMMENTS AND RECOMMENDATIONS CONCERNING  
FORECASTS AND INFORMATIONAL UPDATES

- Need to have a sliding forecast which is periodically updated, e.g., change the hourly forecast to a 3/6/12/24-hour forecast with 3-hour updates; or update (validate) original forecast at more frequent intervals.
- The number one priority should be to get better temporal and spacial resolution weather information (forecast models and observations) to the pilot. This is necessary in order to enhance the credibility of the forecasts, thus improving confidence in the information. The NWS, FAA, and DOD should provide the means to do this improvement. The improvement and timeliness is especially needed in winds and temperature aloft data. This could require some specialist training.
- The forecasting of ozone locations should receive continuing development by affected airlines. Further, the exclusion of ozone from the interior (passenger compartment) of aircraft should receive continued effort by affected airlines.
- The FAA should make the weather products available so that the user can tap the data base. This could be accomplished through the use of home computers.
- The USAF and U. S. Navy research facilities, in cooperation with other government agencies, should continue to develop and improve forecasting techniques and methodologies.
- Cargo and corporate aviation need better weather information (nowcast and forecast) at destination airports where they fly but cannot obtain it at this time, since they fly during times when aviation weather facilities (FAA & NWS) are not operating. This problem could be solved by using a sponsor for affected airports. This should, at least, be accomplished for airports having instrument approach procedures.

While this committee's comment was made relative to general aviation, it carried over to other aviation pilots (i.e., passenger, cargo, corporate, and military). The importance of weather training was also stressed by Col. Chede (Brazilian Air Force/Retired), who stated:

"...all pilots-in-command should be trained on Operational Aeronautical Meteorology so that they will be able to get a right weather concept from the left seat. They should be taught much more on the interaction between aircraft and the atmosphere and much less on meteorological theories that explain the general nature of weather phenomena."

Before proceeding to comment on the next table, it is noteworthy to state that the importance of PIREPs to aviation was illustrated by the remarks and recommendations made by members of this workshop.

Tables 7, 8 and 9 have comments and recommendations which, for some, have become routine at the workshops. However, rather than disregarding them because they recur at almost every workshop, this is an excellent reason for applying additional efforts toward attempting to solve them or greatly reduce their effect on aviation. We should examine new ways to attack the problems. One of these ways could be the use of satellite

TABLE 7

COMMENTS AND RECOMMENDATIONS  
CONCERNING ICING

- A consortium-operated car wash de-ice facility could have many advantages for the industry and should be examined.
- There exists a need for better forecasts for icing. This is easily seen, particularly for an aircraft on final approach, which finds a go-around is necessary; but cannot climb due to ice.
- Icing reports need standards and reporting categories to gain better utilization, i.e., terminology needs to be improved.
- More icing research is needed; sensors need to be developed; and there is a lack of icing observations, which needs to be corrected.
- Standards need to be developed relative to ice, snow, etc., for runway conditions.
- Continued research is needed in ice-phobics and other materials relative to icing.

TABLE 8

COMMENTS AND RECOMMENDATIONS  
CONCERNING SEVERE WEATHER

- The National Weather Service thunderstorm reporting system should be retained in its present format to insure maximum utilization.
- It is both practical and highly desirable that development of severe weather-related decision making should play a major role in the early training of pilots.
- Significant meteorological training for airline operations is important and should be done in a training concept, not as a required check flight. All aspects of aviation need to get better weather training.
- The Air Force Flight Dynamics Laboratory, in conjunction with NASA and the FAA, should initiate a program to (1) develop electromagnetic data for cloud-to-ground lightning from an airborne observation point; and (2) develop design guidelines and test procedures for fuel tank and electronic systems lightning protection.
- The importance of additional lightning research was stressed relative to composite materials and fly-by-wire systems.
- The military use of satellite meteorological data is unlimited; however, training, increased data base, and their participation in various efforts, such as PROFS, is necessary if maximum utilization is to be obtained.
- Efforts should be continued towards the resolution of the effects of heavy rain on aircraft performance.



TABLE 9  
COMMENTS AND RECOMMENDATIONS  
CONCERNING WIND SHEAR

- Additional efforts should be conducted in the identification of the meteorological conditions conducive to the microburst wind shear phenomena. This will involve additional efforts relative to the Joint Airport Weather Studies (JAWS) Project and a look at the Doppler Acoustic Sounder as a detector.
- A program should be established to increase the awareness of wind shear hazards.
- Wind shear characteristics should be incorporated into training programs and should include two items: (1) the recognition of a severe situation; and (2) the understanding of aircraft performance in that condition.
- Recommend the development of ground-based and airborne wind shear detection system for the detection and avoidance of hazardous low-level wind shear.
- Wind shear advisories need to have standards established for communicating assessed severity.

meteorology. As David Winer (FAA/Office of Environment and Energy) puts it, "the future looks very promising for satellites..." However, we should not expect a quick solution to all our problems as a result of using satellite data.

It is also worth noting that the attendees are concerned about problems other than weather and its effects. A list of general recommendations is presented in Table 10. These, while considered to be equal in importance to others, did not fit into the customary breakdown. A major point to be made relative to this table is concerned with training. The first item listed is a coupling of four recommendations which were made at the workshop. The recommendations from the Training/Simulation Facilities Committee probably expresses the need for a pilot certificate:

"One suggestion to insure that each candidate for a pilot certificate understands the basics of meteorology and severe weather is the sectionalization of the FAA written exam. A pilot who then fails any portion of the meteorology section of the exam should be required to retake that portion of the exam before being permitted to take his flight check for a particular certificate. A review of weather should also be included on a recurrent basis, such as in the biennial flight reviews."

## CONCLUSIONS

As stated in the title of this article, six workshops have been conducted; and it has been the general belief that they are well worth the time and effort. In fact, it is generally believed that they have improved with each additional one. It is quite possible that similar workshops will be conducted in the South Pacific (possibly Australia) and in Europe; thus attesting to the benefit of the past workshops.

To conclude this article, a quote from Col. Paul Try (USAF, Pentagon) expresses the author's feelings:

"In summary, I wholeheartedly support the concept of this workshop and look forward to addressing further how DOD activities match up with the workshop recommendations. However, I offer two challenges: first, to attempt to prioritize the recommendations based on need, cost and achievability; and second, to consider the re-evaluation of weather parameters really needed for the reliable and consistent automated observation capabilities."

A noteworthy event of the workshop was the awarding of certificates to some of the participants by the Honorable Lamar Alexander, Governor, State of Tennessee.

TABLE 10  
COMMENTS AND RECOMMENDATIONS  
OF GENERAL INTEREST

- The need exists to have more adequate, required and recurrent weather training for all aspects of the aviation community (general aviation; corporate, cargo, passenger and military pilots). Weather training is also needed relative to and prior to implementation of Automated Flight Service Stations. Training is also needed in order to make the best use of advanced flight simulation.
- A need exists for more research in the area of indirect sensing of winds and temperature using satellite data.
- The capability of using satellites for communication of weather information to en route aircraft needs to be improved.
- Weather satellite interests should solicit the attention of the aviation professional groups (e.g., ATA, IATA, ATCA, ALPA, NBAA, AOPA, etc.), in order to encourage their constituents to provide accurate and detailed PIREPs to be used in the correlation of satellite data. Explain future benefits to be derived from such correlations to provide the capability to detect and/or forecast CAT and other aviation-related phenomena.
- The FAA and USAF Air Weather Service should investigate ways of reducing the time required to process and disseminate PIREPs. This should be a "no-hassle" method of insuring their dissemination to agencies (users) requiring them. This possibly could be accomplished by utilizing VOR voice channel. In addition, a method needs to be developed so that late-night PIREPs will not be lost (i.e., a need exists for 24-hour periods and automation of Central Weather Service Units (CWSU).)
- The FAA needs to start CWSU operations earlier in the day in order to provide more current input to Central Flow Control Facility, which is used for aircraft flow restrictions.
- The FAA/DOD users need to explore integration of aviation weather systems operations in order to improve information and to reduce duplication.
- The FAA should review and amend its policy regarding the prohibition of striated markings on the Category 2 runways.
- There is a need to assure the availability of weather observations at all public airports as a condition of provision of approach control service or for a certified instrument approach.
- NASA should vigorously pursue the establishment of standards for runway friction measurements and operational reporting of that data.
- Airport management should bring together local interest (carriers, corporate aviation, FBOs, politicians, etc.) to determine the extent to which closed or reduced-hour tower facilities could be utilized for weather data acquisition/dissemination, and possibly, airport advisories; to seek FAA authorization for the use of those facilities and equipment where reduced hours of operation are in effect.
- The DOD and FAA should encourage the military to increase its use of VHF when operating within the air route traffic system.
- In order for corporate aviation to be most effective, they need hard copies of weather and NOTAM information.
- The aviation community does not feel they should have to pay for a product that requires modification to satisfy their needs.
- The monies from the trust fund should not be impounded and put into the general fund.
- Information on clothing, which have the tendency to create a static spark, should be disseminated to all fuel handlers at airports in order to eliminate the possibility of its being used by ground-handling personnel.

## REFERENCES

- Camp, D. W., and W. Frost, 1977: Proceedings: First Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, 8 - 10 March, 1977. NASA CP-2028/FAA-RD-77-173, Washington, D.C., 327 pp.
- Camp, D. W., and W. Frost, 1979: Proceedings: Third Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, 3 - 5 April 1979. NASA CP-2104/FAA-RD-79-49, Washington, D.C., 183 pp.
- Camp, D. W., and W. Frost, 1981: Proceedings: Fifth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, 31 March - 2 April 1981. NASA CP-2192, Washington, D.C., 143 pp.
- Frost, W., and D. W. Camp, 1978: Proceedings: Second Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, 28 - 30 March 1978. NASA CP-2057/FAA-RD-78-99, Washington, D.C., 252 pp.
- Frost, W., and D. W. Camp, 1980: Proceedings: Fourth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, 25 - 27 March 1980. NASA CP-2139/FAA-RD-80-67, Washington, D.C., 275 pp.
- Camp, D. W., W. Frost, E. M. Gross, J. F. Sower, and A. R. Tobiason, 1981: Summary Report of the Fifth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems. Preprints, International Conference on the Aviation Weather System (Montreal), AMS, Boston, pp. 233-238.
- Frost, W., D. W. Camp, J. W. Connolly, J. H. Enders, J. F. Sower, and H. L. Burton, 1979a: Second Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems. Bull. Am. Meteorol. Soc., 60, 38 - 45.
- Camp, D. W., W. Frost, J. W. Connolly, J. H. Enders, and J. F. Sower, 1980a: Third Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems. Bull. Am. Meteorol. Soc., 61, 25 - 29.
- Camp, D. W., W. Frost, J. W. Connolly, J. H. Enders, J. F. Sower, E. M. Gross, and A. R. Tobiason, 1980b: Fourth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems. Bull. Am. Meteorol. Soc., 61, 1628-1633.
- Frost, W., D. W. Camp, J. H. Enders, J. F. Sower, and J. W. Connolly, 1979b: Survey of Meteorological and Environmental Inputs to Aviation Systems. Paper presented at the WMO Technical Conference on Aviation Meteorology, Geneva, 5 - 9 November 1979, 30 pp.
- Frost, W., and D. W. Camp, 1982: Research Areas Relative to General Aviation Weather Problems. Paper presented at AIAA 20th Aerospace Sciences Meeting, Orlando, Florida, 11 - 14 January 1982, 12 pp.



## **SECTION II WELCOME REMARKS**



## INTRODUCTION AND WELCOME

Walter Frost:

Welcome to the Sixth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems. We are, particularly, pleased that so many of you have been able to attend our workshop in this period of tight funds for travel. I have asked Dr. Ken Harwell, Dean of the University of Tennessee Space Institute, to welcome you on behalf of the Institute.

Ken Harwell:

On behalf of the faculty and staff of the University of Tennessee Space Institute, I would like to welcome you to the Sixth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems. We are extremely happy to have you on our campus again. UTSI has hosted the past five meetings of this group, so that many of you have been here enough to be considered "home folks."

We are extremely proud of the research that has been carried out at UTSI in the area of aviation weather by Dr. Walter Frost and his Atmospheric Sciences Laboratory. Walter has received international acclaim for his work on microbursts. He is one of our Research Division Directors at the Space Institute and we are thankful for his leadership in this workshop.

The Space Institute is a unique place with numerous outstanding faculty members working on over 100 sponsored research projects with combined budgets of over \$8 million. Research is being carried out in many areas that should be of interest to many of you. I hope that you will take the opportunity to visit with our faculty and staff and tour our research facilities.

Again, let me welcome you to our campus and invite you to visit with us again soon.

Walter Frost:

We would also like to bring you greetings and welcome from NASA, one of the key sponsors of this workshop. We have asked John Theon, from NASA Headquarters, to be our Banquet Speaker tonight and also to welcome you on behalf of NASA. John is the Chief of the Atmospheric Dynamics and Radiation Branch of the Environmental Observation Division in the Office of Space Sciences and Application at NASA Headquarters. We will introduce John in a much more formal manner tonight at the banquet; but right now, I would like to call upon John to welcome you on behalf of NASA.

John Theon:

I will be very brief. I'm here, principally, because my boss, Shelby Tilford, the Division Director, had hoped to be here but was suddenly pressed into a trip to China. I know he would have liked to have been here, himself, to wel-

come you; but, in his absence, I will just say that we're happy that you are here and happy to co-sponsor this meeting and look forward to a very fruitful couple of days. Thank you.

Walter Frost:

The Panel Session, which we are about to convene, has representation from major Federal Government agencies that sponsor our workshop and also supply the weather support in the various forms needed by the users. We have asked each panel member to first give a brief presentation on their current efforts, and where they see the system going in the future. We will, then, open the panel to discussion from the floor. To moderate this panel, we call upon a very good friend of the workshop. He is one of the original sponsors; I want to say the grandfather of the workshop, but he doesn't like me to say that. As a moderator, he has a great deal of experience to bring to bear. He has worked with both NASA and FAA, which are two representatives of our panel. He has also dealt with NOAA and DOD on many occasions. We are, therefore, confident that he has the right questions and prompts to make in terms of getting the Panel Session going. He will introduce the panel to you and welcome them on our behalf. I would like to call upon Mr. John Enders, whom we call Jack. He is President of the Flight Safety Foundation in Washington, DC. I think most of you know Jack; but if you don't, you will know him after this session.

Jack Enders:

It's kind of like coming home again, here at the Space Institute. Before we get into the Panel Session, I'd like to share a thought with you that might stay with you throughout the remainder of the conference. Since leaving NASA and going with the Flight Safety Foundation, my exposure to safety problems has expanded a considerable amount through contact with our worldwide membership. At a recent international meeting, one of the safety officers of a major world airline made the statement, "If I do not know about a problem in my airline, it does not exist for me; therefore, I can do nothing to alleviate the problem." That really gets to the point of why we are here. When NASA, NOAA and FAA started this workshop series six years ago, it was with a view toward breaking down the compartmentalization that inevitably is involved in any sophisticated system. The one common interest that all of us have here is weather and its effect on the system. Yet, we often find ourselves out of touch with each other when we really need, from time to time, to be sharing with each other our conceptions of weather problems and possible solutions.

With that, we'll move on into the Panel Session, in which, as Walter said, we will endeavor to present you with a little bit of background information to take with you to the interactive sessions.

# **SECTION III**

## **PANEL SESSION**

### **PRESENTATIONS**



## Aviation Weather Services

Charles H. Sprinkle  
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### INTRODUCTION

The National Weather Service (NWS) has a vast operating program. NWS personnel are found at over 400 facilities in the 50 states and elsewhere. Altogether, NWS has about 5,000 people working in meteorological, hydrological and oceanographic operations. In one year, about 3.5 million forecasts and warnings are issued. In addition, countless individual briefings and services are provided on a routine but unscheduled basis.

The provision of forecasts and weather warnings to the general public and to specialized users is the heart of the NWS operations. The offices most involved in the production of forecasts are the Weather Service Forecast Offices (WSFOs), while warnings are issued by both WSFOs and the more localized Weather Service Offices (WSOs). In general, WSFOs' areas of responsibility conform to state boundaries. However, larger and more populous states (Texas, California, New York, etc.) contain more than one WSFO, while some smaller states are within the area of responsibility of WSFOs of neighboring states (Connecticut and Rhode Island are within WSFO Boston's area of responsibility). WSOs generally serve the urban areas of the nation by providing a more localized and tailored service. Usually, several WSOs lie within the area of responsibility of a WSFO. Forecasts issued by the WSFOs go to the general public as well as to specialized users. A sizable effort of a WSFO is concerned with meteorological support to the aviation industry. The National Meteorological Center (NMC), located near Washington, DC, provides the WSFOs with guidance material used in developing forecasts.

Warnings from both WSFOs and WSOs are issued for severe weather such as hurricanes, tornadoes, severe thunderstorms, flash floods and extreme winter weather. The National Severe Storms Forecast Center (NSSFC) in Kansas City, and the National Hurricane Center (NHC) in Miami, provide the main support for the warnings program.

Another important aspect of NWS operations is the acquisition of meteorological data. Such data are collected from the land, the sea and the upper atmosphere by people from many countries. Additionally, satellite information is sent to many receiving stations on the ground.

### BACKGROUND

The primary responsibilities of the NWS are to:

1. Provide warnings of severe weather and flooding for the protection of life and property;
2. Provide public forecasts for land and adjacent ocean areas for planning and operation;
3. Provide weather support for:
  - a. Production of food and fiber;
  - b. Management of water resources;
  - c. Production, distribution and use of energy; and
  - d. Efficient and safe air operations.

The principle role of the NWS is to issue severe weather warnings to save lives and to minimize property loss. The United States has a greater variety of severe weather than any other nation in the world. Hurricanes, tornadoes, floods, flash floods, thunderstorms and severe weather take an inordinate number of lives and cause thousands of injuries each year, despite advances in technology and skills in forecasting and warnings. It is estimated that the cost to the nation is well over \$2 billion per year from these extreme weather events.

No other industry is more sensitive to weather than aviation. There are more than 825,000 certified pilots operating over 230,000 aircraft from an excess of 15,000 landing places in the United States. The last decade has been a period of rapid change. The aviation community expanded at a rate unprecedented in our Nation's history. A more mobile, safety conscious, and energy conscious society has become more demanding of sophisticated weather information. The NWS has been working to meet the challenge of getting timely and accurate weather information to the end user --- the pilot.

Providing weather service to aviation is a joint effort of the NWS, the Federal Aviation Administration (FAA), the military weather services and other aviation oriented groups and individuals. Because of international flights and a need for worldwide weather, foreign weather services also have a vital input into our service.

The cooperation between the FAA and NWS for the provision of aviation weather services and communications is described in a 1977 Memorandum of Agreement between the two agencies. One of the major responsibilities of the NWS is to produce the forecasts and warnings in support of the aviation community. The dissemination of this weather information to pilots is the responsibility of the FAA and of the air carriers, themselves. The NWS's responsibility in this area stems from the Federal Aviation Act of 1958 (Section 101: Title 49, Section 1301, United States Code) as amended, and the NWS's

organic authority contained in Title 15 of the United States Code.

## NATIONAL WEATHER SERVICE BASIC SERVICES

Today, the NWS provides a broad range of products to the aviation community. Fifty-two WSFOs prepare airport terminal forecasts three times per day with amendments as needed for nearly 500 airports in the 50 states and in the Caribbean. Our offices also produce about 300 individual route-oriented forecasts three times per day for the 48 contiguous states. Thirteen of these offices prepare area forecasts twice a day of general weather conditions over the entire country. These same offices issue in-flight advisories of hazardous weather conditions due to turbulence, icing, strong low-level winds and/or broad areas of low clouds or restricted visibilities. In-flight advisories of dangerous conditions associated with thunderstorms are issued each hour by a dedicated aviation unit at the NSSFC in Kansas City.

The question of how this information can best be conveyed to those with "a need to know", including FAA specialists and controllers and users of the National Airspace System, in the most timely and efficient manner possible has been of concern for some time. We have been working with the FAA to alleviate this problem. The problem is especially critical when hazardous weather is involved. To illustrate this point, one merely has to look at the statistics on aircraft accidents; they don't change much from year to year. Of the 4,000 to 5,000 general aviation accidents occurring annually, 20 to 25 percent of all fatal accidents are weather-related. In many cases, these weather-related accidents involve the loss of a large number of lives. The most recent examples are the accidents that occurred at New Orleans and in Washington earlier this year.

Many things have been done and are being done to improve the flow of the most vital real-time weather information to the users of the National Airspace System.

The Center Weather Service Unit (CWSU) program began in 1978. This cooperative effort with the FAA represents a major effort to improve the dissemination of real-time weather information by controllers to the pilot in flight. The program expanded from 13 to 21 Air Route Traffic Control Centers (ARTCCs) and was completed early this year with the addition of a fourth meteorologist position in each center. The program uses NWS meteorologists located in ARTCCs to provide meteorological consultation and advisories to air traffic personnel.

The CWSU meteorologists monitor major air traffic terminals and routes of flight in the ARTCC's area of responsibility. They inform the flow controller, the weather coordinator and meteorologists at the Central Flow Control Facility

(CFCF) in Washington of any weather changes that may affect the safe and efficient flow of air traffic. They also coordinate with the WSFOs to ensure the most accurate terminal and area forecasts and in-flight advisories possible with the existing state of the science. When such coordination is not possible, they modify and update those forecasts for the internal guidance of the ARTCC's controllers.

The CWSU meteorologists have the following specific responsibilities:

1. They monitor all weather reports, forecasts and warnings issued by responsible WSFOs in and near the Center's area of responsibility and remain aware of any weather conditions which might adversely affect air traffic operations.
2. They work closely with the FAA officials having responsibilities and/or interests in aviation safety for their Center area.
3. They provide detailed briefings of current and forecast weather several times per day for the ARTCC's area.
4. They serve as consultants to the ARTCC controllers, to en route flight advisory service specialists and to central flow meteorologists in situations where hazardous weather impedes the normal flow of air traffic requiring an alternate traffic routing to be determined.
5. They use weather radar and satellite receiving equipment, along with other available data sources, to forecast and alert ARTCC controllers to weather conditions affecting or expected to affect air routes within their area of responsibility.
6. They concern themselves with the efficient collection of Pilot Reports (PIREPS) received at the ARTCC and their distribution to the weather communications network. Working with the weather coordinator, they obtain specific PIREPS from their areas of concern.
7. They participate in special programs involving localized meteorological phenomena which could affect aircraft operations at specific airports.
8. They conduct weather training sessions for air traffic controllers and specialists and are, themselves, involved in various NWS training programs aimed at up-grading their use of satellite and radar information as it affects aircraft operations.

Several improvements are currently being implemented in ARTCCs to improve the flow of vital weather information. Namely, the FAA's new high-speed communications system, the Leased Service A System, is being installed to aid in more rapid accumulation of weather intelligence from places outside the Center. Also, color



radar monitors to aid in the identification of hazardous weather phenomena, especially thunderstorms, are being installed for the use of CWSU meteorologists. The program is expected to be completed in the Spring of 1983.

The main area of concern is the communications capabilities from the CWSU meteorologists within the Center and to appropriate control facilities within the Center's area of responsibility including, but not limited to, Terminal Radar Approach Control (TRAC) facilities, towers, En route Flight Advisory Service (EFAS) and Flight Service Station (FSS) facilities. At the present time, in most centers, this is done manually, by telephone. It is hoped that at some time in the future, the CWSU meteorologists will be able to automatically communicate weather intelligence (by utilizing the Leased-Service A System, to appropriate locations both inside and outside the ARTCC.

## **NEXT GENERATION WEATHER RADAR PROGRAM**

The Next Generation Weather Radar (NEXRAD) is the new weather radar system being developed by the Department of Defense, the FAA and the NWS to replace the current aging weather radars; and at the same time, improve the detection of hazardous weather. NEXRAD will have Doppler capability. The Joint Doppler Operational Project (JDOP) demonstrated the feasibility of Doppler technology in field tests at NOAA's National Severe Storms Laboratory (NSSL) in Norman, Oklahoma, during the period 1976-1979.

Since radial velocities of raindrops in a storm can be measured, Doppler radar offers marked improvements over conventional radar for early and accurate identification of thunderstorm hazards, especially tornadoes and squall lines. The NEXRAD System will also allow for a more complete geographical coverage than the present radar network. Initial field installation is expected to begin in 1987 and be completed by 1990.

## **JOINT AIRPORT WEATHER STUDIES**

The Joint Airport Weather Studies (JAWS) Project field experiment was conducted from May 15 this year in and near Denver, Colorado. This project, under the auspices of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, and the University of Chicago, is sponsored by the National Science Foundation (NSF), the FAA, NOAA and NASA. Three ground-based Doppler radars and several research aircraft participated in the JAWS program. An examination of the data collected is currently ongoing and is expected to give new insight into the nature and behavior of thunderstorms and their inherent threat to aviation.

## **AUTOMATED AVIATION ROUTE FORECAST**

An objective of the FAA's Flight Service Automation Program (FSA) is the capability for a pilot to obtain a self-briefing through direct access terminals or voice-response systems. The

area-type aviation weather forecasts, however, are currently not in a format readily adaptable to this new technology. This indicates a need for new methods of describing area-type aviation weather phenomena. NWS proposed a new grid data base concept, the Aviation Route Forecast (ARF). Development of a working ARF prototype has been undertaken by the MITRE Corporation in McLean, Virginia, for the FAA and NWS. A graphical forecasting system has been developed in which the NWS forecaster inputs geographic contours to a computer to describe the effective areas of meteorological parameters. Overlayed on the forecaster's multi-state forecast area is a 22 x 22 mm grid. As each weather contour is completed, the computer determines the affected grid squares and sets them accordingly in the data base. Subsequently, the grids surrounding a pilot's requested route are retrieved and a briefing is assembled.

The ARF input workstation and output briefing information package underwent an operational evaluation this summer. Recommended software and/or hardware changes from this operational test will be considered this fall, and refinements to the equipment and procedures made.

## **WHERE DO WE GO FROM HERE?**

A number of technological possibilities for detecting severe weather, for communicating, integrating and displaying the data, and for disseminating weather forecasts and warnings can be foreseen. The geostationary satellite, the Doppler radar, automated weather observing systems and a whole range of ground-based remote sensing systems will permit far better detection of severe weather than currently possible. This new capacity to observe the small-scale atmospheric circulation will improve severe weather detection and subsequent warnings. Low-cost mini- and micro-computers now make it possible for our forecasters to assimilate the information and make decisions quickly.

The automation of surface observations and of area, route and terminal forecasts will play an important role in the NWS's aviation weather services program in the eighties. The primary emphasis of the aviation program will shift towards preparing detailed terminal forecasts for a six or eight-hour period and for providing severe weather information in a timely way to the air traffic control system.

## **CONCLUSION**

It is recognized that more than any other transportation system, aviation is affected by weather. The transitory and often short-lived nature of hazardous weather phenomena mandates the need for the latest weather information to be in the hands of aircrews, air traffic controllers, dispatchers and others concerned with the safe and efficient use of the NAS. Achieving a firm and comprehensive physical understanding of the processes that determine the character of thunderstorms is without question one of the most important challenges facing the atmospheric sciences community today.

There will be scientific and technological opportunities that will enable us to make significant improvements to the services we provide the aviation community. The NWS, the FAA and other

Federal agencies as well as the academic community have joined in a comprehensive, cooperative effort to meet the challenge before us today.

## NASA's Aviation Safety - Meteorology Research Programs

Roger L. Winblade  
NASA Headquarters  
Washington, DC

One of the research areas included in NASA's subsonic aircraft programs is that of aviation safety. A major element in that aviation safety research program addresses meteorological hazards to flight. The various research programs in meteorological hazards have been underway for a number of years; some are phasing out; some are just starting. I'd like to go through what we now have currently underway, what we've done recently, and some of the ideas on where we think we're going.

In general, the areas that we have in the meteorological hazards program are: severe storms and the hazards to flight generated by severe storms; clear air turbulence, an area that's been with us a long time; icing; warm fog dissipation; and landing systems. Landing systems are included since once you make your way through what may be a hazardous atmosphere and end up on the ground, you are landing in what is a very large, heavy, fast tricycle; and the interface at that point becomes a rather critical area. We have also recently completed some experiments (one of the few areas in which satellites have been used as a source of data for us) relative to remote sensing of ozone. Also using satellites in a slightly different mode, as a data relay system, we have looked at the possible benefits to be derived from using essentially real-time wind data for flight planning.

In the severe storms research, started in 1977, we are attempting to identify what, in fact, is the makeup and the structure of severe storms, principally thunderstorms. Ideally, one would like to do this kind of work with remote sensing; but in many areas, it is impossible to remotely sense the kind of information that is needed. One such program that has become very successful, and is hardly a remote sensing program, is the F-106 that is used to fly into thunderstorms in an attempt to obtain direct lightning strikes. One hundred seventy-six (176) strikes have been obtained in three (3) years. It is a highly instrumented airplane. This instrumentation is now allowing us to identify or characterize lightning strikes in flight and identify and hopefully predict the effects of lightning on aircraft systems and structures.

A second area where remote sensing may be used in the future will be to sense gust environments. Currently, it is a matter of obtaining the data

by experiencing the event. That is, we are attempting to find the microstructure of the gust environment.

Through the use of a specially instrumented B-57 aircraft, we are flying into turbulence and measuring the lateral gust gradients over the span of the airplane. This program is thus attempting to identify the effect on the airplane of gust gradients of the size of the aircraft. This program will be discussed later in detail by Warren Campbell of NASA/Marshall Space Flight Center.

NASA is also a participant in the Joint Airport Weather Studies (JAWS) program which is delving into the physical properties and generation of low-level wind shears. In addition to providing flight support via our B-57 aircraft, we are also involved in certain areas of data analysis. Dr. John McCarthy of NCAR will speak on this program in detail later in the Workshop.

Clear air turbulence (CAT) has been a hazard and an annoyance throughout the years as airplanes have changed in character from propellers to jets. The drag to mass ratio has changed. The upsets experienced by the large transports represent a severe hazard in air travel. Initially, as we learned to cope with the upsets, flying procedures were implemented to alleviate the effects during the turbulence encounters; the hazard was lessened significantly. Yet, we are continually reminded that the problem has not been solved. The last encounter I can recall directly was a DC-10 encountering severe CAT over Denver, and there were a number of people hurt in the airplane. No severe damage was sustained by the aircraft; but it was an unanticipated encounter with turbulence. NASA has undertaken a long-term study of devices that may have potential for remote detection and early warning of CAT. The Laser-Doppler Velocimeter (LDV), the infra-red radiometer and the microwave radiometer all have potential, but they all have shortcomings. We are, however, continuing to explore methods of overcoming these shortcomings.

Dr. Joe Shaw of Lewis Research Center will be giving a detailed discussion on our aircraft icing research program. This area has re-emerged as an area of concentration for NASA, centered directly about the icing research tunnel facilities at the Lewis Research Center. In addition, we have found that we need data on atmospheric

icing to correlate with the icing tunnel predictions. Thus, we instituted the Twin Otter Icing Flight Program at the Lewis Research Center.

Atmospheric fog is a hazard regardless of aircraft avionics. Taking the pilot's vision away in that very final stage of touchdown and rollout creates hazardous situations. NASA is exploring a technique, which introduces electrically charged particles into warm fog which causes it to precipitate. At the present time, it appears to have potential but we must carry the research further for final proof.

As I alluded to earlier, the interface between the flight vehicle and the ground is one that periodically comes back and bites us in terms of accidents. As the airplanes get bigger, the approach and landing speeds become higher, the take-off gross weights go up (always with the potential for rejected take-off, and the runway-tire interface becomes very critical. Micro-scale description of this interface has been and will continue to be an area of significant research effort for us to insure safe runway operations in all types of meteorological conditions.

Figure 1 shows the effect on stopping distance of water, packed snow, or ice on the runway. The diagonal breaking vehicle (DBV) stopping distance ratio illustrates the magnitude of the runway surface condition on the amount of runway needed to stop the vehicle. As runways are used continuously, and become coated with rubber on the touchdown end, there is an additional increment of stopping distance that, in some cases, can be equal to the normal dry runway stopping distance. The significance of obtaining this kind of information is in pre-flight planning or for training simulation. An awareness of the true situation must be instilled in the flight crew as to what the runway-tire interface is when the weather and runway conditions change.

Relative to monitoring ozone concentrations which may be hazardous to crew and passengers, we were able to use, during March through May of 1981, existing sensors on the Nimbus 7 Satellite to detect ozone concentrations. These values could then be correlated with aircraft measured concentrations. The success of this program now provides, in our minds, a very real potential for forecasting ozone concentration that are at or above the critical levels in sufficient time to avoid them through flight planning. The alternative, of course, is to carry additional equipment on the airplane for filtering.

One final program I want to mention is one in which aircraft equipped with inertial navigation systems as well as transponders transmitted wind data derived from the aircraft via a satellite link back to the Goddard Space Flight Center.

Using these data to re-plan the flight and estimate the effect on fuel performance of real-time wind information showed statistically significant savings in fuel, where potentially possible. In the North Atlantic runs, wind data that is normally used to establish the North Atlantic tracks can be up to 24 hours old. If that can be reduced to eight (8) hours, a saving, on a fleet-wide basis, of 2% to 3% of the fuel is possible. This translates to saving a few billion dollars every year in fuel costs.

The foregoing summarizes NASA's current aviation safety research programs that are related to meteorology. Each of these major programs will be discussed in detail by the various researchers that are here or will be here through the remainder of the conference.

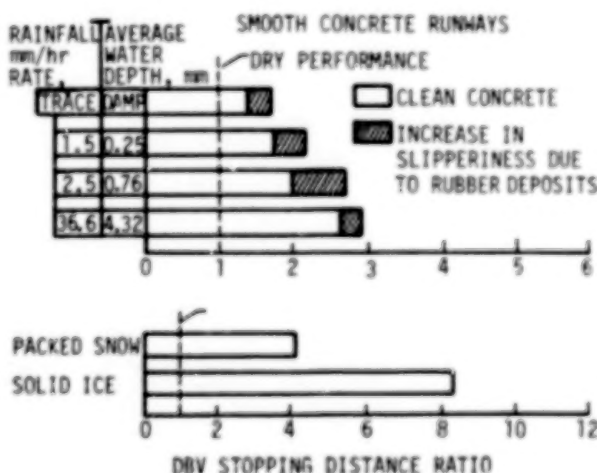


Figure 1. Surface Contaminants Evaluation



# Department of Defense Meteorological and Environmental Inputs to Aviation Systems

Col. Paul D. Try

Director, Office of Environmental and Life Sciences  
Under Secretary of Defense for Research and Engineering

Good morning, I'm Colonel Paul Try, Director of the Office of Environmental and Life Sciences in the Office of the Under Secretary of Defense for Research and Engineering. Within this office, I have oversight and policy responsibility for the research and operational meteorological and environmental programs of the Military Services.

I was particularly pleased to be invited here today to participate in this workshop because I am a great supporter of the concept behind this gathering. In particular, the concept of bringing together the various disciplines of the aviation community with the operational meteorologists and research atmospheric scientists. The workshop concept and the development of recommended actions are functions which receive my full support. In reading the summary recommendations and background from the past workshops, I noted, but did not agree with, most of the past criticisms of this workshop concept, except one. I would agree that after six workshops covering the field very well, it is probably time to tackle the tough job of prioritizing the recommendations (possibly within disciplines) and noting the most appropriate agencies to focus on the solutions. Where else will you find a better group with the years of experience and knowledge to attempt this job? One cautionary note:

-- in prioritizing recommendations you must consider the factors of 1) need, 2) cost and 3) ability to achieve or the availability of a state-of-the-art solution. My choice for top prioritization is not the cancer cure type recommendation, but the more near to mid-term achievable recommendation.

Let me now move on to some comments concerning the goals and research programs within DOD associated with meteorological support to aviation systems. Since the workshop theme relates meteorology, aviation and satellite facilities, I thought I would start off with linking all of these disciplines together.

Within the limited time here, I naturally cannot describe all of the numerous programs within the Army, Navy, Air Force and Marine Corps related to weather and aviation safety; however, I would like to give a brief overview and illustrate some of the DOD efforts.

The goals we have within DoD are similar to those of other agencies as they pertain to improvement in safety of flight. There are several areas for concern. As our aircraft systems become more sophisticated, we are

finding in many cases a greater sensitivity to meteorological conditions. The use of composite materials and fly-by-wire technology are just two examples of advances which have already illustrated weather-related programs. Low experience aircrews, single seat, single engine, high performance aircraft and the need for all weather combat readiness, couple together to indicate critical needs for improved research, design, training, operational procedures, weather observations and forecasts.

Integral to the DoD flight safety efforts related to the environmental parameters of icing, wind shear, turbulence, lightning and other severe weather phenomena, are the research activities designed to improve the observation and forecasting of these hazardous phenomena.

I'll just briefly cover some of the R&D activities related to the DOD environmental support services and discuss them by the parameter of interest: icing, lightning, wind shear, turbulence and other severe weather phenomena.

Aircraft icing research activities are primarily centered in the Air Force and the Army. The Navy's efforts are primarily associated with supporting the FAA helicopter icing studies through the use of an instrumental P-3 aircraft and with an experimental evaluation of surface implanted sensors to determine water depth and ice on runways. The Army efforts center around activities at the Cold Regions and Engineering Laboratory (CRREL) and the Army Aviation R&D Command (AVRADCOM).

The CRREL researchers are conducting detailed investigations on icing, ice adhesion, icing of rotating blades, freezing precipitation, freezing rain, sleet and other forms of natural icing conditions. Also, studies are being performed on the physical properties of ice, ice accumulation rates, and methods of snow and ice removal from roads and runways. CRREL's work in the area of forecasting of icing conditions is part of a general effort that addresses the total problem of aircraft icing with strong emphasis on helicopter icing problems. CRREL has developed a numerical simulation of icing accretion rates in terms of the structure parameters and the atmospheric parameters of temperature, liquid water content and drop-size distribution. This allows evaluation of the sensitivity of accretion to each of these. CRREL is also initiating work on forecasting of icing at the mesoscale level with the intent of eventually providing the tactical commander with local forecasts of icing probability for combat display rather than "blanket" forecasts.

The Air Force has a small but significant aircraft icing program at the Air Force Geophysics Laboratory (AFGL). This program is specifically designed to improve the techniques for forecasting aircraft icing conditions. There are five phases of this research:

- 1) the evaluation of the Rosemount ice accretion detector for aircraft;
- 2) the 1979-81 collection of detailed data sets using an HC-130 aircraft flying in icing conditions within the vicinity of a rawinsonde balloon station;
- 3) the comparison of these icing data with the current Air Force Air Weather Service (AWS) icing forecasting techniques;
- 4) the development of improved techniques using standard available meteorological data as input; and
- 5) the development of a method for producing a worldwide climatology of aircraft icing based on standard archived data.

The Air Force AWS has the responsibility for operational aviation forecasting for both the Air Force and the Army. In a related effort to that within AFGL, the AWS is working to improve its ability to forecast the key meteorological input parameters for icing forecasts: en route temperature, cloud occurrence and cloud liquid water content. The ability of any icing forecast method is only as good as the basic meteorological input parameters. The improvements achieved in forecasting these basic parameters at the Air Force Global Weather Center will couple with the AFGL and the CRREL work to improve DOD capability for forecasting both fixed wing and helicopter icing conditions. The Air Force Aeronautical Systems Division (ASD) has developed a structural icing model (AEROICE) which is under evaluation and improvement and ASD testing of portable aircraft ground de-icing equipment is underway.

Research and development into aircraft in-cloud turbulence is most active within the Air Force. In conjunction with NASA, AFGL has been conducting tests with a ground-based Doppler radar and an instrumented NASA F-106B aircraft at Wallops Island, Virginia, to collect the data needed to develop on-board sensors for turbulence avoidance and to improve forecasting techniques. The AWS is currently evaluating the Air Force Flight Dynamics Laboratory (AFFDL) comparative analysis of turbulence impacts on various types of aircraft within similar meteorological conditions. Since the meteorological conditions which cause severe turbulence for a T-39 will have a different result on a C-5 or B-52, each as a function of in-flight gross weight, AWS is looking at using the AFFDL report to develop a standard to scale from and to more accurately report and forecast aircraft turbulence. The AFGL efforts also include a CO<sub>2</sub> Doppler LIDAR measurement program and a modeling effort to

improve our wind shear observation and forecasting techniques.

The most significant DOD program related to observing and forecasting the major parameters related to aircraft safety (i.e., turbulence, lightning, wind shear, hail and icing) is the joint Department of Commerce/Department of Defense/Department of Transportation (DOC/DOD/DOT) Next Generation Weather Radar (NEXRAD) Doppler radar program. With many of the benefits and operational complexities of the Doppler weather radar already demonstrated in a joint operational test, the NEXRAD program offers an existing state-of-the-art advance over our current thunderstorm/tornado and associated severe weather phenomena forecasting immediately upon installation. The NEXRAD radars are required to replace the failing 1950's technology radars in service today. These new radars offer improved tornado detection lead times (from a current lead time of less than one minute to an average of 20 minutes), doubled detection rates for the severest storms, reduced false alarm rates for thunderstorm severe winds and hail (up to 50% reduction), improved low-level extreme wind shear identification and forecasting, improved icing level location, and improved hail forecasting. The AFGL, in conjunction with the joint NEXRAD program office and the NOAA National Severe Storms Laboratory (NSSL), is developing and testing the software to automatically identify and forecast these critical severe weather phenomena using the NEXRAD basic Doppler input data.

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In addition to the significant aircraft lightning strike research and testing being done at AFFDL, the Navy has an active program focused more toward the detection and location of lightning. The Naval Air Development Center is evaluating an on-board severe storm avoidance sensor for the P-3 anti-submarine warfare aircraft. This low-cost passive detector will be flight tested at the Naval Air Test Center this year in conjunction with the Wallops Island ground-based lightning detection and ranging

system. The P-3 aircraft, due to its number of flight hours flown and mission profile, is the most frequently lightning-struck aircraft in the Navy inventory. This system will allow passive navigation around lightning activity which is often important for an aircraft not desiring to emit radar signals. The joint NASA/AFGL icing test at Wallops Island is also designed to evaluate the airborne lightning hazards with respect to the measurable meteorological parameters. The Navy is now in engineering development of a Lightning Position and Tracking System (LPATS) developed by the Office of Naval Research with Naval Air Systems Command assistance. This ground-based system detects the unique broad-based magnetic field waveform of the cloud-to-ground lightning stroke and displays its location, intensity and movement on a video screen. The LPATS system is currently undergoing field tests at NAS Cecil Field, Florida, with the central station located in the Naval Oceanography Command Detachment office for operational evaluation.

Whatever the environmental aircraft flight safety hazard, the DOD is involved in evaluating and improving the observation and forecasting of the phenomena. In most cases, the DOD efforts are either joint or complementary efforts and are coordinated through the Office of the Federal Coordinator for Meteorology and Supporting Research.

You will note that I've skipped over the most basic of the meteorological inputs to aviation,

that being the accurate observation and forecast of ceiling and visibility. Both the Air Force and the Army are working in improved visibility sensors with the Army using the laser approach and the Air Force using the forward-scatter/nephelometer approach; and both addressing different aspects of automation of these sensors for fixed base and remote combat deployment. As a participant in the Joint Automated Weather Observing Programs with NWS and FAA, DOD is most interested in pursuing the fully automated surface observation; however, before we all spend further research dollars on the automation of presently reported weather parameters, it may be the appropriate time for all of us to join together and re-evaluate the true requirements for aviation weather observations. The past-stated need for slant visual range (SVR) data might be an example where great sums of money could have been spent to produce unneeded data using hazardous towers or non-eye-safe lasers.

In summary, I wholeheartedly support the concept of this workshop and look forward to addressing further how DOD activities match up with the workshop recommendations. However, I offer two challenges: first, to attempt to prioritize the recommendations based on need, cost and achievability; second, to consider the re-evaluation of weather parameters really needed for safe landing operations to lead the way for the reliable and consistent automated observation capabilities.

## Federal Aviation Administration Weather Program To Improve Aviation Safety

Robert W. Wedan  
Office of Associate Administrator for  
Development and Logistics  
Federal Aviation Administration

The Federal Aviation Administration (FAA) issued the National Airspace System (NAS) Plan in December 1981 to provide for systematic developments that insure the safe and efficient movement of both civil and military aircraft. This plan was developed to meet the system capacity requirements resulting from the increased growth expected by 1993 of:

- 85% in domestic air carrier passenger miles
- 231% in commuter passenger miles
- 67% in the number of hours flown by general aviation
- 112% in the hours flown by rotary wing aircraft.

The implementation of the NAS Plan will improve vital safety services to aviation. These services include collision avoidance, improved

landing systems and better weather data acquisition and dissemination. The Plan focuses on the current system and improvements that must be made in the immediate future to meet the projected needs and demands of aviation.

Efforts to improve aviation weather services initiated a few years ago are integrated into this plan. The program to improve the quality of weather information to pilots, controllers and flight service station specialists for safe and expeditious operation of aircraft encompasses the following major programs:

- Radar Remote Weather Display System (RRWDS)
- Flight Service Automation System (FSAS)
- Automatic Weather Observation System (AWOS)
- Center Weather Processor (CWP)/Center Weather Service Unit (CWSU)



## ● Next Generation Weather Radar (NEXRAD) Development

While these are the major efforts, it is significant to note that a total of 22 separate programs are affected to some degree by the FAA commitment to upgrade weather detection and dissemination. For example, the FAA plans to replace its outdated air traffic control computers and displays. As part of the new display consoles, severe weather will be presented to the controllers along with aircraft targets. Work still remains to determine the best way to present the weather data and to what degree the center meteorologist will interact with the display. In any event, all of what I present here, together with the weather element in the rest of the 22 programs, all have the purpose of serving the controller and the pilot with essential and real-time weather information that supports both efficient and safe flight operations.

## RRWDS

Radar Remote Weather Display Systems will be able to access six (6) levels of precipitation intensity (reflectivity) from 134 radars nationwide. By mid-1983, all 20 conterminous Air Route Traffic Control Centers (ARTCCs) - Center Weather Service Units (CWSUs) and 44 En route Flight Advisory Service (EFAS) positions will have dedicated and dial-up rapid access to these National Weather Service (NWS) and FAA radars. Data from these sources will provide six-level color weather contours displayed on CRTs and be used by the CWSU meteorologist and Flight Service Station (FSS) specialists. Data from the RRWDS will be used primarily to develop CWSU advisories to controllers on location, intensity and movement of hazardous convective weather and by the EFAS specialists to alert pilots to the same hazards.

We have tested and will continue to evaluate techniques for presenting weather radar contours on controllers en route plan view displays. By 1985, it is expected that RRWDS in the form of contoured reflectivity data will be available to en route traffic controllers on their Plan View Displays via the Center Weather Processor and the existing 9020 en route Air Traffic Control processor. As mentioned earlier, the manner of presenting weather will be evaluated in parallel. Contouring severe weather on the controller's PVD appears to be a practical approach for the 9020 equipment. The future sector suites provide the option of presenting weather in an area by shades of grey on color fill-in. Questions that must be addressed include scope clutter and other workload or interpretive questions and computer loading.

## FSAS

The Flight Service Automation System incorporates high-speed communication and computer processing techniques dedicated to collecting, formatting, editing, distributing and displaying weather data required by the FSS specialists

for pilot briefings and dissemination to pilots. A national weather data base (the Aviation Weather Processor) containing United States, Canadian, Mexican and Caribbean data will be available for rapid access by 1985. Digitized weather radar data, digitized weather graphics, a nationwide file of pilot reports and data from the surface weather reporting stations will be available to the pilot on a timely basis through the use of the FSAS and the high-speed digital communication lines from the National Airspace Data Interchange Network (NADIN). Pilots will be able to obtain more accurate and up-to-date pre-flight briefings from the FSS specialist with the elimination of the manual "paper shuffling" tasks of sorting out only those data required for a particular flight. The automated filtering of these data will be based on departure times, altitude of flight and route of flight.

Initially, Flight Service Data Processors will be installed in 14 of the 23 existing ARTCCs by 1984, which, in turn, will drive remote equipment located at 41 FSS sites. Enhanced Flight Service Data Processing Systems, which include improvements on the aforementioned 14, will be installed at the other nine ARTCCs, which will drive remote equipment located at a total of 61 FSS sites by 1988. To support these improved systems, two Airport Weather Processors will be installed at Salt Lake City and Atlanta, respectively, to process data for the total system. Details of the operation of the FSAS are presented in the article "Meteorological Impact on ATC System Design" by Frank E. Van Demark.

## AWOS

Automated Weather Observation Systems (AWOS) are planned for operational evaluation at 15 airports during 1983 and 1984. These evaluations are the culmination of a series of tests on observation systems and/or weather sensors obtained from manufacturers which began in 1975 and ended in July of 1982. The AWOS will have the capability of measuring a range of surface weather parameters consisting of wind speed, wind direction and wind gusts, temperature, altimeter setting, visibility and cloud height/ceiling. The system includes automated data entry, data display, data recording, remote maintenance monitoring and failure reporting and both voice and Very High Frequency (VHF) communications output. The six major subsystems and components of AWOS are:

1. Sensors and field electronics
2. Sensor processors
3. System processor
4. Voice output
5. Communication processor
6. Remote maintenance, monitoring and data recording.

This program represents one of several major decisions made during the preparation of the NAS Plan. That is, to dedicate the VOR voice channel for dissemination of real-time weather. Another possible use of the voice channel, to broadcast digitized weather radar data, is mentioned below.

Future efforts to improve AWOS will involve refinement of algorithms for processing operational parameters and evaluation of new sensors, e.g., thunderstorm location and present weather. FAA implementation of 700 systems nationwide will begin in 1985 and be completed by the end of the decade. It is expected that private aviation interests and the Airport Improvement Program\* grants will add another 900-1000 systems over the same time frame.

## CWP

The Center Weather Processor is being developed into a real-time, fail-safe system for receiving, storing, processing and distributing weather information for the support of National Airspace System operations. It will be the central system for collection and dissemination of weather information and located in each Air Route Traffic Control Center. The CWP will contain alphanumeric weather observations and forecasts, weather charts, radar weather data and weather satellite images. The first system is planned to be implemented in 1985. The CWP will provide the Flight Service Data Processing System with radar weather contours derived from the RRWDSs and support an automated work station for the CWSU meteorologists. Through enhancements, the CWP will add interfaces and will eventually support en route sectors through the 9020 computer and its replacement, and advanced systems such as the en route sector suite and the Mode S data link. The air traffic control weather advisories developed by the CWSU meteorologists and automatically disseminated by the CWP will be used by pilots, controllers and FSS specialists to reduce the chances of aircraft encountering hazardous weather situations and to increase the efficiency of operations in the NAS. An additional major enhancement to the CWP will be the mosaicking of NEXRAD (see next section) and Airport Surveillance Radar weather channel data.

## NEXRAD

The Next Generation Weather Radar System is being developed jointly by the Department of Transportation (FAA), Department of Commerce (NWS) and Department of Defense (Air Force Geophysics Laboratory). The FAA objective in this program is to provide Doppler weather radar information on the location, measurement and movement of potentially hazardous convective weather and its attendant hazards to aviation. NEXRAD weather data products will include automated reflectivity, radial velocity and spectral width maps, severe weather alerts, hazardous weather contour maps and echo top maps and a free text message on equipment status.

FAA requirements for NEXRAD include:

- En route coverage from 6,000 feet to 70,000 feet.
- Terminal area coverage within 30.0 nautical miles of the terminal from 500 to 20,000 feet.
- Coverage within 10.8 nautical miles of selected airports from 200 - 10,000 feet.
- Complete radar volume update cycle of 5 minutes with partial volume sampling in 1 to 2.5 minutes.
- NEXRAD products for use by meteorologists, controllers, FSS specialists and eventually pilots via MODE S data link.

The FAA is actively participating in the development and technical studies phase of the program by funding the following:

- Radar clutter suppression techniques
- En route siting and update rates
- Scanning strategies and interface techniques.
- Algorithms and mosaicking techniques to provide hazardous weather contours to the CWP/CWSU.
- Operational processing and display techniques.
- Verification of data transmission rates between NEXRAD data acquisition sites, the radar product generator and the principle user processors.

The FAA airspace coverage, data update rate, data resolution, accuracy and system availability are substantially more demanding than those identified by other participating agencies. Deployment of the NEXRAD network radars begins in March 1987 with five radars. One hundred and fifty-five more will be added during the 1988-1991 period.

## OTHER RE&D PROGRAM

In addition to the foregoing major weather programs, there will be research, engineering and development efforts:

- To continue studies of wind shear, downbursts and microbursts through the Joint Airport Weather Studies (JAWS) program for application in aircraft simulations and avionics certification. Details on JAWS under the direction of the National Center for Atmospheric Research are in the paper "The Joint Airport Weather Studies

\*Airport and Airway Improvement Act of 1982

Project" by John McCarthy. We expect that the knowledge gained by JAMS will directly affect both the NEXRAD and CWP Programs to insure that the severe weather is adequately detected and the data properly processed.

- To develop instrumentation to detect and follow wake vortices behind aircraft for use in developing procedures to reduce separation standards between aircraft on take-offs and landings in order to increase airport capacity.
- To improve the wind shear warning capability for pilots through certification of airborne wind shear warning systems. The FAA has issued an advisory circular that describes acceptable simulation test criteria, wind field modeling data and minimum performance parameters for evaluating candidate systems. The airborne systems will complement the low-level wind shear alert systems (LLWSAS) that are currently operational at 58 airports and are scheduled for installation at 51 more.
- To evaluate products required by the CWSU meteorologist and develop the specification of the automated CWSU workstation by supporting the NWS Prototype Regional Observing and Forecast System (PROFS) at Boulder, Colorado. The intent of PROFS is to automate the analysis of inputs from automated surface weather observations, Doppler and conventional radars, special microwave upper air wind measuring equipment, and visible and infrared satellite data to produce a variety of new weather products. See the paper "Prototype Regional Observation and Forecast System" by John Hinkelman, Jr., for a detailed description. Again, we expect to see the results of this program support other FAA programs, in particular, the CWP and CWSU workstation.
- To improve the dissemination of weather information to general aviation aircraft by demonstrating a low-cost technique for getting weather radar data into the cockpit. In a recent demonstration at Columbus, Ohio, using the SWR 74C weather radar, a small ground-based microprocessor, the Zanesville VHF Omni Directional Range (VOR) station and the Appleton and Rosewood VORs, an on-board microcomputer which is interfaced with the VOR receiver and an inexpensive printer, weather radar precipitation intensity data were transmitted directly to pilots within 50 - 75 miles of the VOR. In addition, the data include the relative location of nearby VORs mapped on the printout. This provides an orientation to the pilot's present position to permit him to plan changes, if necessary, to this route.

With the installation of Mode S facilities and airborne transponders, another method of acquir-

ing weather data will be available. On a request/reply basis, rather than by broadcasting over the VOR, the pilot will be able to access the weather data base, which resides in the CWP. This includes thunderstorm data.

To some extent, the VOR broadcast of ALOS and weather radar data may be redundant. However, four factors mitigate the question. First, not all aircraft will have Mode S transponders and terminals for acquiring weather. Second, installation plans for Mode S will call for high altitude coverage and, at some future time, coverage to 6,000 feet. This compares to current coverage of VORs to the minimum en route altitude. Third, broadcasting data by VOR does not appear to cause a saturation problem in areas of severe weather although a voice priority interrupt will still be required. On the other hand, the Mode S data link may prove to become quite saturated as the full use of the link for air traffic control becomes clearer. Finally, the airborne equipment required for receiving ground weather radar data, if designed to anticipate the Mode S data link terminal, will contain common use equipment elements. These include the display, keyboard and microprocessor. In summary, we currently expect that these two methods of transmitting weather data to the pilot can be very compatible.

- To provide in conjunction with the NWS an improved Aviation Route Forecast (ARF) technique for presenting forecast and observed data for routes and areas. The ARF data base will consist of forecast weather information at grid points covering the entire U. S. Information at each grid point on cloud cover, visibility, weather, convective activity, freezing level and icing and turbulence will be stored. When a route or area is entered, the computer will retrieve data from those grid points applicable to that particular route or area. The ARF system will have an input workstation for NWS meteorologists and a software routine for output which is planned for integration in the FSAS.

In summary, Figure 1 illustrates the future FAA aviation weather systems data sources.

The foregoing are active programs. When completed, the FAA will have a superior weather system in operation to assist all aircraft to operate safely and expeditiously in any weather environment.

## REFERENCES

- U. S. Department of Transportation, Federal Aviation Administration: National Airspace System Plan, December, 1981.
- J. Lynn Helms and Siegbert B. Poritzky: The National Airspace System Plan, Astronautics and Aeronautics, June 1982, pp 50-61.

Proceedings: Fifth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems, University of Tennessee Space Institute, March 31 - April 2, 1981, NASA CP-2192 and DOT/FAA RD 81/67, 1981.

Federal Aviation Administration FAA: Advisory Circular AC 120, Criteria for Approval of Airborne Wind Shear Detection Systems, October 1982.

\*NESS: National Environmental Satellite Service  
\*NMC: National Meteorological Center

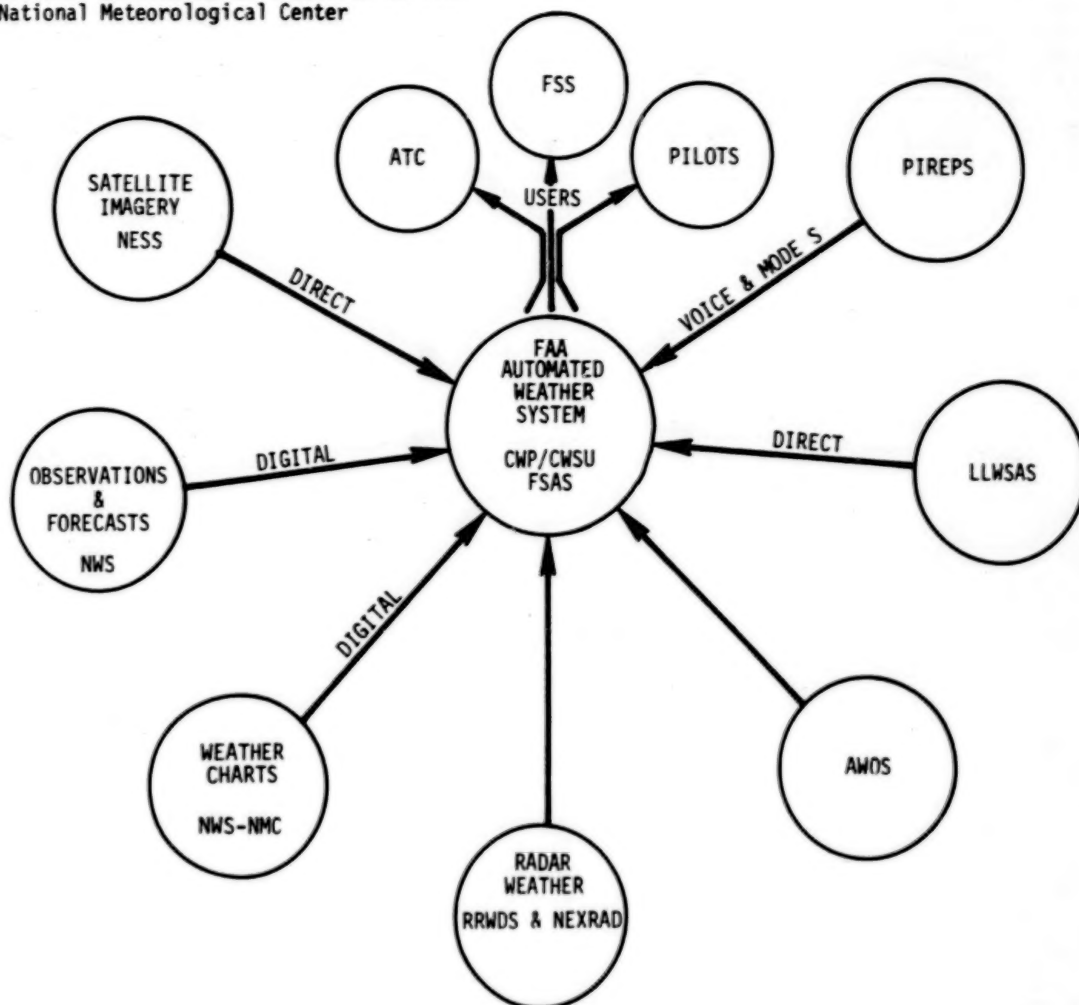


Figure 1. Future FAA Aviation Weather Systems Data Sources

### Discussion From the Floor

Moderator: John H. Enders  
President  
Flight Safety Foundation, Inc.

**QUESTION:** Jack Hinkelman, PROFS Program

I would like to ask Charlie Sprinkle if he feels that centralizing the area of forecast program in Kansas City has stepped forward or backward?

**RESPONSE:** Charlie Sprinkle

As I indicated before, the Site Specific Terminal Forecast will remain at WSFO's. The area forecast and in-flight advisories will be centralized. I, personally, think it's a



step forward. Anybody that has had the chance to visit our facility at the NSSFC would realize the great amount of equipment and the greatest technology that we have is out at NSSFC; but we can't afford to put that at 52 locations. Also, we will have a dedicated staff with the sole purpose of concentrating on the services to aviation. At present, the area forecast is issued twice daily from nine offices in 48 states. When we go to Kansas City, it will be issued three times daily. We are making no changes in the program in Alaska or Hawaii; but I feel strongly that this is a step forward, due to the technologies and dedicated staff in Kansas City.

**QUESTION:** Jack Enders

Charlie, on that topic, let me ask: Does the centralized forecast staff have an adequate chance for face-to-face interaction with the pilot community? I've always felt that, and of course my age is showing here, there was a good learning process going on both ways in the days when the pilot would talk face-to-face with the forecaster. The forecaster had a good indication on how he was doing as a forecaster in almost every briefing, and the pilot would have a chance to interact in a way that the automated systems don't permit, due to limited flexibility. Do you feel that the central forecasting staff will have an opportunity to have some kind of currency in keeping close to the pilots in the front end of the operation, up there fighting their way through the thunderstorms?

**RESPONSE:** Charlie Sprinkle

Well, back in the days when we had 10 forecasters and 100 pilots, one-to-one worked very well. You can see from the plans that the FAA are developing that we would like to provide that service, but we're no longer able to provide a true one-on-one relationship in most instances. Yes, in the weather service, we have something called a familiarization program, where several times a year, our forecasters apply to an airline; ride up front in the cockpit of a commercial airliner; interact with the pilots. So, I certainly don't think there would be any lessening on that fact, either.

**QUESTION:** Jim Luers, University of Dayton Research Center

I would like to address this question to everyone in general and, perhaps get a response from each one, individually, if possible. I noticed in the review of all your programs that no one mentioned any research on heavy rain effects on aircraft; and I was wondering whether you people have any programs. I'm sure you're aware of what's been done on the problem, and I am wondering if you believe there is not sufficient data available on which to justify such a research program; or whether the heavy rain phenomena is not con-

sidered to be important. Why is there no discussion of research programs on heavy rain effects...hopefully, I can get some response from everyone.

**RESPONSE:** Roger Winblade

We are aware of the potential problem. There have been some studies done. Currently, we are in the process of developing a wind tunnel and analytical test program. The opinions are quite varied as to the significance, at least in an aerodynamic sense, of the significance of heavy rain as a detriment to aerodynamic performance. Our general opinion is that we don't have enough data, and we are setting the wheels in motion to generate some hard data to determine the effects of heavy rain.

**RESPONSE:** Jim Luers

I have one comment. I think we have made some pretty strong accusations as a result of an analysis of five previous aircraft accidents, which, we believe, were caused essentially by heavy rain and not by wind shear. I think those accusations should either be debunked as being inaccurate and our errors pointed out, or somebody should take some positive action to see whether our accusations are correct or not. As of yet, I'm waiting for somebody to criticize our analysis of those accidents. Maybe we are wrong, but I believe we deserve an answer to the accusations we've made.

**RESPONSE:** Leo Boyd, Tennessee Eastman Company

I'm representing Corporate Aviation, here... also General Aviation from my private flying. It is interesting to listen to a lot of this research that's going on and our observation from real life in the difficulty we're having with receiving weather information. The basics are that we frequently cannot even get the FSS (Flight Service Station) to answer the telephone; so we have a problem in motivation of people. How many FSS specialists are in the coffee shop? How many are over at the briefing desk? How many are answering the telephones? Sometimes, you will see maybe one person answering the telephone out of about a half-dozen on duty. When we go to the sophisticated 61 super flight service stations system, how are we then going to get them to answer the telephone? Are we going to have to bypass the FSS altogether? Right now, approximately 85% of general aviation is left swinging in the wind with minimum to no weather/NOTAM information. We fly and we get the weather for safe operations and for potential legal implications of what we're running into. Most of what we're talking about here is not getting through to the user. I would like to add the some few FSS provide excellent service; it is unfortunate these are in a minority.



**RESPONSE:** Bob Wedan

Just a comment on that. You certainly state the problem accurately. The one thing that I should mention is that there's a strong awareness of the problem within the FAA. Prior to the time that the automated Flight Service Stations come on line, we are expanding a capability which exists in two locations: one is in the Washington, DC, area and the other in Columbus, Ohio. Weather information is obtained through an automated voice-response to your flight plan information, where you use a touch-tone telephone to enter your plans into a computer. You get back a voice response from the computer. It gives you information that you request in such categories as current weather, winds aloft and terminal forecasts. This information by-passes the FSS briefer and has improved the access of data to the pilot by telephone. We plan to expand this interim service prior to the full development of the automated flight service station equipment. At that time, the voice-response system will be available nationwide.

**QUESTION:** Demos Kyrakis - R & D Associates

On the B-57 Gust Gradient Program, do you make high-speed temperature measurements along with your other measurements? By high-speed, I mean sub-millisecond-type measurements.

**RESPONSE:** Dennis Camp - NASA/Marshall

We did make temperature measurements on the aircraft. The data was recorded at a 40-Hz rate, but the upper frequency cut-off for the instrument was 1/2-Hz. The B-57 Gust Gradient data, including temperatures will be published when available.

**QUESTION:** Demos Kyrakis

The reason I'm asking the question is that we were involved with the airborne laser lab and were making atmospheric measurements for the purpose of looking at the optical degradation of the laser beam. Now, in order to do this, you have to measure the density of fluctuations in the atmosphere. This is done by using two hot wires...one with a high over temperature measures  $\rho V^2$ ; the other measures temperature fluctuations to determine the density. In many of our flights, we found that the gust loading... or, if you will, the shaking of the airplane... correlated, not with changes in velocity, but with very rapid changes in temperature of the millisecond or tens of millisecond time scale. I would say that gust measurements, wind velocity measurements or gust gradient measurements, may be an incomplete set of data in order to try to correctly model the effect on the aircraft structure.

**QUESTION:** Warren Campbell - NASA Marshall

At what altitude range were you seeing this?

**RESPONSE:** Demos Kyrakis

The altitude variations were from between 6000 feet MSL and 30,000 feet MSL. At White Sands Missile Range, 6000 feet MSL is about 1000 feet above ground level. Sometimes we went as high as the tropopause; however, most of the measurements were made at lower altitudes. Our main altitude of interest, where most of these measurements were made, was around 10,000 feet MSL.

**QUESTION:** Ted Mallory, Republic Airlines - Atlanta

Mr. Wedan mentioned, I believe, research and development being made on in-flight weather radar pictures transmitted from remote sites, and I was wondering...has there been any other research and development on actually taking radar displays from remote sites and transmitting them directly to the aircraft's radar but actually of any radar system for pilots to look at in the air as well as on the ground when preparing for the flight on the next leg?

**RESPONSE:** Bob Wedan

I've heard there are commercial companies looking into the idea of establishing a dedicated VHF frequency to transmit the information which is available to the public on the ground to the cockpit. This is exactly what we have been talking about, except that it would be provided as a commercial service as an alternative to an FAA provided service. The data that would be available would be available in either case as a signal in space that is captured by the VOR receiver and processed for display to the pilot. The way that the information is presented to the pilot, we believe, is within the realm of commercial development. There are lots of ways that this can be done. The weather radar screen could use a picture which is oriented with north at the top or you could have a track-up presentation. These possibilities are beyond the scope of what we're currently concerned with. At the moment, we're concerned only with the question of whether or not to provide the ground-based information to the pilot as a basic signal that can be presented in some fashion.

**QUESTION:** Fred Ostby, Severe Storms Forecast Center, Kansas City

I wanted to add comments to a couple of questions that were previously asked concerning the centralization of aviation forecasts. Charlie answered the first question about whether we were moving backward or forward, but I wanted to augment that a little bit by saying that previously, aviation forecasts were inconsistent as issued between the boundaries of the different Aviation Area Forecast Centers; however, since the forecasts will now be issued from only one area forecast center, we will have a more consistent product, I think

across the country. Although aviation forecasters had the responsibility for the in-flight advisories and the area forecast, because of staffing problems and a multitude of other duties going on at a typical forecast office, a previous problem has been the difficulty in continuously monitoring the weather conditions for AIRMETS and SIGMETS. I think a dedicated staff having that sole responsibility is an important feature and will translate in terms of a better product. The second question that I wanted to comment on had to do with how it was felt about the centralization of the forecast as far as interface with pilots. That does not represent any change in the area forecast structure as it was previously set up; it did not have an interface with any pilots at all, so that the centralization does not change that particular policy. The interface comes more localized in FSS and things like that. Finally, I would like to ask a question of the FAA about what the next steps are as far as the ARF Program is concerned and in what sort of time frame do you see it?

**RESPONSE:** Bob Wedan

ARF is planned as an enhancement to the automatic flight service station program. The capability will be available in the 1986-87 time frame.

**QUESTION:** John Prodan - AV-CON

This must be "pick on FAA period for right now." Again, this is for Mr. Wedan. I noticed that in the presentation the information emphasis was going to the controllers. The user, the pilot, is responsible for the safety of his flight and, if I'm a general aviation pilot, I can hardly afford to fly these days because of the added tax that just went on and the maintenance costs that keep going up. I can't add all these other things to my airplane, which will allow me to receive the information that is currently available in the centers. Is there going to be a change in FAA policy so that center controllers will give information to the pilot if he asks for it? Maybe a "yes" or "no" answer is what I'm looking for.

**RESPONSE:** Bob Wedan

The problem that we've had so far partly relates to the accuracy of the information presented to the controller. I believe that with the presentation of better data to the controllers, the transfer of that information to the aircraft in flight will happen.

**FOLLOW-UP RESPONSE:** John Prodan

The controllers in the past have been extremely reluctant to pass any information along - good or bad. I'd like to have the information, even if it is mediocre information, as long

as it's not wrong information. I don't think that's been the question. I think the question has been are they going to be authorized to disseminate weather information? If so, will general aviation pilots be given an opinion as to the severity of the weather...is it as bad as they seem to think or are they going to be painting an easier picture?

**RESPONSE:** Bob Wedan

Well, first of all, I cannot comment about possible policy changes regarding the transfer of hazardous weather to the pilot. But, as you will notice, aircraft that are flying too low and a low-level alert is provided to the controller, this information is provided to the pilot. So, we do have a history, I believe, of transferring hazardous information to pilots, whether it's another airplane flying too close; flying too low near a mountaintop or a city skyscraper. I believe that severe weather is another hazard that will be transferred. The difference between the weather and these other examples, at the moment, is the confidence of the controllers in the weather information provided to him.

**FOLLOW-UP RESPONSE:** Terrell Wilson -  
FAA Air Traffic Service

I might add that we are investigating alternative means of relaying weather to pilots, hazardous weather in particular. We recognize that it is a problem at times for air traffic controllers to relay weather data to pilots; their primary responsibility being the separation of air traffic. One means of disseminating hazardous weather is currently being tested in Florida, southern Alabama, Georgia and South Carolina. This effort is referred to as Hazardous In-flight Weather Advisory Service (HIWAS). We continuously transmit pre-recorded hazardous weather data over selected VORs.

This is expected to provide weather data to pilots in a timely manner while reducing the requirement of the controller having to interrupt his primary responsibility to relay this data.

**QUESTION:** Jim Sullivan, U. S. Air

Mr. Wedan, you commented on the low-cost units you can put in the cockpit. Do you have any idea of what low-cost would be on these units?

**RESPONSE:** Bob Wedan

We've made an estimate. Clearly, it doesn't make any sense if the units are up in the price range of airborne weather radar. So it has to be considerably less in order to make any sense at all. Our estimate, and this is including a times 2 uncertainty factor, is the order of \$2,000. ●

**RESPONSE:** Jim Sullivan

We have been, to answer Ted's question, talking with Kavouras about up-linking radar information, color radar, right to the cockpit. Again, you run into the problem of saturation. You can't handle all the requests that come through to do this.

**QUESTION:** Vince Oliver, Environmental Satellite Data

Charlie Sprinkle mentioned that the new policy was that the user had to pay for some of the services. I want to ask Bob Wedan about the FAA and these 15,000 airports that don't have weather or weather service. Does the FAA have any policy or program about how far down the line it will go before the user has to foot the bill?

**RESPONSE:** Bob Wedan

I think that the closest I can come to answering that question is to say that we intend to buy about 900 - 1000 of the automatic sensors (AWOS equipment). We would expect that this number will be doubled through private purchases. Our primary interest is to get systems into the field to extend the data base available to pilots as soon as possible, particularly to support operations at airports that are not tower-equipped but have instrument approach procedures.

**QUESTION:** Jack Enders

I want to insert a question and then we'll go to Russ Lawton and, then, back to Leo Boyd.

I have a question on the information transfer problem - getting information through a crowded ATC communications system. My question is for Col. Try, Roger Winblade and Bob Wedan. Is there anything in any of DOD's, NASA's or FAA's human factors programs that are dealing directly with the problems of information transfer in the weather systems; and by that, I mean problems that occur in automating the transmission of information to bypass the human ATC controller so as to format it in a way so that the pilot who is receiving it is getting the maximum intelligence out of it? Who wants to give that a first go?

**RESPONSE:** Bob Wedan

We have a branch in the engineering and development, called the Pilot Factors Branch, that is intended to address some human factors problems. I think one critical question that will be addressed over the next few years relates to communicating information from the ground to the air through the Modes Data Link. This capability provides an alternative to voice communications. Where we've got crowded situations, particularly in terminal areas, the

data link can unload the voice channels. However, this raises workload questions for both controllers and pilots. That's something that we're going to be looking at.

**RESPONSE No.2:** Roger Winblade

We do have a fairly extensive human factors effort and a major part of that is the study of information flow and transfer. The state of the analytical capability of that field is not sufficiently precise enough to be able to differentiate information that is uplinked, whether the information is through another human, or automated, or whatever, in terms of an analytical procedure. We're still working on pretty gross levels in terms of information flow.

**RESPONSE No.3:** Col. Paul Try

There is quite a bit of human factors work that goes on in DOD; but it is more directly related to the weapons system involved. Whether you're in an aircraft cockpit or in a tank, there's a significant amount of human factors work that goes on as it relates to the system, to include information transfer to the pilot or to the tank driver. In terms of the specifics of weather data, I don't know of any program that is designed to look at just the weather aspect; but if you're getting information up into a cockpit, there's considerations of all of the aspects which include all of the control functions and weather as well as everything else.

**QUESTION:** Russ Lawton, AOPA

Thank you, Jack. I don't want to reiterate since a couple of people have already expressed the frustration of trying to obtain weather on the ground and in flight; but I think the concept of trying to up-link information, especially with proliferation of airborne weather radar would certainly cut down on proliferation of paper in the cockpit. You know the old saying: "When the weight of the paper equals the weight of the airplane, you're ready to fly...cut down". But as far as obtaining the weather information on the ground, I'd like to ask Bob Wedan if any consideration has been given to providing the weather products to independent service so that those folks who have Apple II or TRS-80 or many of the other home computers can do the briefing themselves through a product like that because that definitely seems to be the wave of the future in light of the consolidation and automation of flight service stations. There are only so many weather briefers to go around.

**RESPONSE:** Bob Wedan

The answer is yes. The flight service automation program provides for pilot self-briefing terminal capability. The original idea was that you would go to the operator at the local



airport; sit down in front of a terminal and obtain graphical and alpha-numeric-type data from that terminal. But, at the same time, and as part of the enhancement program, we've been experimenting with techniques that would permit access of the same information with home computer terminals. We've been using the Transportation Systems Center (TSC) for experimenting with those techniques.

**QUESTION:** Russ Lawton

Is there any certain time frame for making it available:

**RESPONSE:** Bob Wedan

I'll have to recall from memory, but I think 1986-87 is about right for this capability.

**MODERATOR:** Jack Enders

Charlie, I think you want to add something to Bob's answer.

**RESPONSE:** Charlie Sprinkle

Just very quickly! We, in the Weather Service, are in the process of completing the installation and operations of our AFOS system. It is our communications system and since we don't allow any external taps on that, we are in the process of making arrangements at the National Meteorological Center to establish four (4) or five (5) what we call "ports" where each port will have a different class of information. Graphics in one, aviation digital forecast in another...many different types of forecast. Those ports will be available to service companies or whoever wants to pay the tab and hook up to them and haul the data away; so we are making provisions for that in the Weather Service, and we expect the initial installations to begin about the middle of 1983.

**MODERATOR:** Jack Enders

Ladies and Gentlemen, we have five minutes to go. I'm going to take four questions: this gentleman here, then Leo Boyd, Ossi back there and Jim Banks. Additional discussion can take place in the interactive discussions.

**QUESTION:** Tom Greer, Salt Lake City Airport Authority

I would like to return to the discussion about the user charges in paying for the system. I recognize that the Airport Development Aid Program (ADAP) funds are now being used for programs in F & E and most of the users that I've come in contact with feel as if they're willing to pay for that; but going back to what Charlie Sprinkle said about the NWS programs being funded out of ADAP, I have three questions:

(1) Has the administration determined that

there is no public benefit from the information that is obtained and derived in the National Weather Service other than that which is disseminated to the aviation community;

(2) If they have, in fact, determined that, and if the ADAP funds should be used to fund National Weather Service programs, what contributions will be made from other agencies, such as highway, schools, cities and all of the other departments that will utilize National Weather Service information;

(3) and, finally, if the aviation user is going to pay for all of these systems, can and will we have the opportunity to recharge these people who will tap into the system and derive the benefits from the information we are paying you to collect for us?

**RESPONSE:** Charlie Sprinkle

Well, first of all, this thing has been active in Congress for over one year and there's been a minimum of comment on it. Initially, the administration determined that the aviation weather service provided by the NWS was a specially tailored product addressed to a very identifiable segment of the population; therefore, they should, in some way, be responsible for the charges incurred by the Government for providing a specialized service. That has been the stance all along. I forget your third question.

**QUESTION:** Tom Greer

If we are going to pay for this information and they're going to use it, can we find a reliable way of charging them?

**RESPONSE:** Who is they and we?

**RESPONSE:** Tom Greer

You're taking the money out of the aviation trust fund!

**RESPONSE:** Charlie Sprinkle

We are not taking any money out of the Aviation Trust Fund at all, sir. The bill states that the Secretary of Transportation shall reimburse the Secretary of Commerce for the costs in providing aviation weather services as it has appeared in the budget for many, many years. That was pulled out of the general taxes. The farmer in Nebraska objected to paying for an aviation weather service.

**QUESTION:** Tom Greer

But, is he paying for an agricultural weather service?

**RESPONSE:** Charlie Sprinkle

That the aviation community was the first one

that was addressed. It was a very identifiable, very organized segment of the population. Whether we will go into...I know we are investigating the agricultural community as well, specifically, a fruit frost service that's provided. So, it's just that the aviation segment is the first one out of the box. It certainly, I do not think, will be the only one out of the box.

**RESPONSE:** Tom Greer

I think the aviation community is going to object very strongly to the fact that they are being singled out as the primary benefactor of National Weather Service programs. You've got the highway administration, the agricultural...what, in essence, the administration is saying is that there is no public benefit to National Weather Service.

**RESPONSE:** Charlie Sprinkle

I think that's very contrary! There is a very identifiable essence to our forecasts that are provided to a very specific segment of the population.

**QUESTION:** Tom Greer

So, what you're saying is that the general population does not benefit, but primarily the aviation community?

**RESPONSE:** Charlie Sprinkle

Not from aviation forecasts, terminal forecasts, area forecasts or in-flight advisory. Those are the things that are being charged, not for the general forecast. That's another pot of money. That's the general revenue OR&F funds.

**MODERATOR:** Jack Enders

Let's move on to Leo Boyd.

**QUESTION:** Leo Boyd

I would like the FAA and the NWS to re-think the no-access-in-the-near-future program by users having stand-alone computers like the TRS-80, the Apple or other types which a corporate operation, or a fixed-base operation, can use to pull weather and notams directly out of your data bank instead of having to use the telephone to try to get a briefing from flight service station personnel. We need hard copy. The FAA thinks so strongly about real-time hard copy that on the certificated carriers, like Piedmont, Delta and others, the command pilot must be given new weather in print form prior to every take-off; and yet for the average pilot in corporate aviation, some FSS briefers become irritated if you take enough time to write down the weather information that he/she is trying to give you, because of the pressure of their workload. We corpor-

ate operators need to bypass this verbal system whenever possible, and go directly into the system. It would help us. If we go to a commercial service like WSI, NWS, UWS, Global Weather Dynamics or other similar services, then we're talking about \$3,000 to \$12,000 or more a year per operator for access charges (depending on size of corporate operation or FBO).

**RESPONSE:** Charlie Sprinkle

Well, again, I don't mean to be facetious, but it comes down to how much do you want it and how much are you willing to pay for it? If you say \$7,000 to \$12,000 is too much and you expect it to be provided by the Government on a cost-free basis, outside of the funds that we are recovering, that's something else; but the agricultural community has something going now called the Green Thumb Experiment where you can use a home computer to access any number of agricultural things. It is run by the University of Kentucky out of Lexington. The aviation route forecast program that we talked about this morning will lend itself to an access of a data base by home computers. That has been demonstrated this past summer by many pilots assessing that situation in Washington, and it doesn't take a very large computer to do it at all. It is something you can buy at Radio Shack and generally carry around and you can access it. So, we are working that way and those things will be available in the future.

**RESPONSE:** Leo Boyd

This is not a question! Just for the record, each one of our aircraft contributes more than \$30,000 a year in direct taxation and user fees just for the price of entry into the airport/airways system. That isn't chicken feed, Gentlemen!

**MODERATOR:** Jack Enders

That's so noted. That's substantial. Now! Back there, Ossi Korhonen, from Finland.

**QUESTION:** Ossi Korhonen, Finnish Met. Inst.

IFR traffic needs visibility measurements in about 100 m steps and ceiling in 100 ft steps, respectively, and the amount of low cloud by 1 octal accuracy. This places a large demand on an unmanned automatic weather station. Also the weather is a very important parameter for flight planning. Will your automatic weather station fulfill these demands when the first ones are installed in 1983?

**RESPONSE:** Joe Sower - NEXRAD Deputy Director

The first automatic weather stations to be installed will not measure visibility to the accuracy stated and probably will not be accurate to an octal in sky cover. The stations should meet all other parameters except present



weather. It is planned that these systems will be enhanced to meet all requirements.

**QUESTION:** Ossi Korhonen

When the severe weather observation techniques are improved, will it have an effect on air traffic control procedures?

**RESPONSE:** Joe Sower

When the air traffic controllers can be assured that the location of the severe weather, in time and space, is accurate, they will use the information as an input to the control function.

**QUESTION:** Ossi Korhonen

Do flight safety investigations relative to wind shear also consider the effect of strong surface inversions on aircraft performance?

**RESPONSE:** Joe Sower

Investigations of the wind shear phenomena will cover all aspects, i.e., microburst, downburst, gust fronts, low-level jets, frontal and inversions where shears are evident.

**MODERATOR:** Jack Enders

Last question from Jim Banks. Then, we'll break for lunch!

**QUESTION:** Jim Banks

Thanks, Jack, I really don't have a question. I just want to make an observation. I've been

sitting here; I hear some very good dialogue, and it seems like we're trying to solve a problem and we haven't identified what it is quite yet. We, last year, went through this same thing. The NWS says we provide aviation weather to aviation community, which is good. Now, I might suggest that most people who are flying airplanes would like to get this weather: this very perishable information. When you put a third party in such as the flight service station, such as the controller (this keeps popping up), the controller gets the weather but the controller doesn't really want the weather unless it has a direct influence on traffic he's got right now...that he's guiding through some cell or something like that. What I'm saying is that anytime the controller is even partly relied upon for getting weather to a pilot or whatever, we don't really have a viable weather dissemination system. I think we're trying to work toward that answer but can't seem to get over the threshold. To the controller, having current weather information on hand is important, but for his or her use as it influences the ATC situation; not necessarily for re-dissemination. Somehow we've got to figure out some way to get weather out to pilots without relying on third parties. We'll never have a complete system until we do.

**MODERATOR:** Jack Enders

Thanks, Jim. I think we'll be getting into that question in the interactive session, will we not? Okay, thank you very much. Before you leave, I think Walter has an announcement. Thanks to the Panel and thank you for your attention.

## **SECTION IV BANQUET PRESENTATION**



# Applications of the Space Perspective to Aviation

John S. Theon  
Atmospheric Dynamics & Radiation Branch  
NASA Headquarters

More than two millenia ago, Aristotle and one of his students documented the relationships between the signs of weather and the direction from which the wind blew. Almost 250 years ago, George Hadley first hypothesized the existence of an organized global circulation cell that still bears his name. Some meteorological reporting networks were organized in Europe by the early 19th Century by Lamark, LaPlace and Lavoisier. Weather observations were gathered by mail in those days, so the data compiled were useful only in the historical sense. Such collections did, however, permit the synthesis of individual reports into a so-called synoptic picture of the weather over a wide area, and the first weather map was drawn by Heinrich Brandes for the date March 6, 1783, in 1820! Hardly a timely forecast!

M. F. Maury published maps of mean wind fields over the globe in 1848, and these were soon put to use by the sailing fleets of the day. It was not until the invention of the telegraph in the mid-19th century that rapid and reliable weather reports became available in a timely fashion. The importance of weather observations gradually became evident, and as the number of stations grew, so did the interest in weather forecasting.

Certainly the introduction and growth of aviation in the early 20th Century increased the interest in meteorology. For as we all know, aviation is clearly the form of transportation most vulnerable to the vagaries of weather.

It was in the early years of this century that significant progress in understanding weather was made with the introduction of the cyclonic and frontal models by Vilhelm and Jacob Bjerknes, Bergeron and Solberg. Their theories explained the three-dimensional aspects of the weather and made it clear that two-dimensional surface observation networks were inadequate for forecasting weather.

It was in the post World War I period that Richardson suggested that the future state of the atmosphere should be predictable from the present state using the first principles of physics. With the linearized partial differential equations of motion, the thermodynamic equation and the equation of continuity, Richardson's "primitive equation" model had to be numerically integrated by hand, a task so burdensome that he estimated it would provide a forecast for 12 hours only after many days of intensive labor!

The development of free-flying rubber balloons and an economical wireless instrument package in the 1930s made it possible to begin sounding the thermodynamics of the atmosphere in three

dimensions on a wide scale. World War II provided an enormous boost to meteorology with the use of airpower becoming a significant mode of warfare. The U. S. Government poured millions of dollars into training and observations. The development of radar also gave added impetus to the science. The next major advance for meteorology came with the development of the electronic computer in the 1950s. Von Neumann and his colleagues recognized the potential for using the first computers to do what Richardson was unable to do...produce an objective forecast in time to still be a forecast!

A very significant advance in meteorology came in 1960 when the first meteorological satellite (TIROS-I) was launched. Even though it provided pictures of clouds which were difficult to interpret because its spinning orientation made navigation and registration of the images a nightmare, it was a breakthrough in elevating our perspective to a large expanse of viewing the atmosphere from above. At last, the meteorologist could see what the present cloud conditions were in great detail over a wide area at a given time.

These views were useful, but not so valuable for short-range aviation forecasting. For, as we all know, weather systems, particularly in smaller-scale weather (often the most severe), can develop over a matter of hours, and observations from a satellite once or twice per day simply miss a great many weather events. It was not until Vern Suomi developed the spin-scan camera for the ATS satellite that satellites began to have a large impact on weather forecasting in general and aviation forecasting in particular. With images of the entire disc of the earth available at 30-minute intervals, and sector scan of more limited areas available every 3 minutes, it became possible to monitor the development and movement of clouds quantitatively. This capability provides not only cloud growth and cloud height information, but cloud motions are good tracers of the wind as well. This technique was applied to the NASA SMS/NOAA GOES satellites and is operational today. These satellites provide the images we usually see on the evening television news.

When this capability to observe the atmosphere almost continuously is combined with the marvels of modern electronics, especially with an analyst in the loop, the full potential of satellite data grows enormously. With devices like the Man-Computer Interactive Data Access System (or McIDAS, for short) digitized computer images can be quantitatively manipulated to determine winds, wind shears, convergent/divergent zones, vertical growth rates of cumulus clouds, etc. These data displayed with an overlaid weather chart provide instant in-

formation to the forecaster, synthesized in virtually real-time.

But the satellite observations need not be confined to images and image manipulation. Satellite measurements of the atmosphere became three-dimensional in 1969 when instruments aboard the NASA Nimbus III satellite made vertical temperature soundings from space. These first sounders used the thermal radiation emitted by atmospheric CO<sub>2</sub> in the 15  $\mu$ m band to determine the vertical temperature profile. Further developments in vertical temperature soundings pioneered by the experimental Nimbus series of satellites permitted us to obtain more accurate soundings by using the 4.3  $\mu$ m emission band of CO<sub>2</sub> and then the 50-60 GHz thermal band of atmospheric oxygen. In the latter case, the soundings are not limited to cloud-free areas as they are with the infra-red. With the development of the NASA TIROS-N satellite in 1978 and its operational follow-ons, the sounding system utilizes a combination of passive infrared and microwave sensors to measure the temperature structure of the atmosphere routinely. With approximately 7000-8000 soundings per day, the satellite soundings provide important information to the numerical forecast models, especially in remote regions where no conventional soundings are available such as vast oceanic areas and over many third-world nations.

As I indicated, the early satellite soundings demonstrated that we could obtain soundings from space, but they left much to be desired in terms of accuracy. Thus, their early use sometimes made a forecast worse and they were not used operationally for almost 10 years. NASA continued to develop methods to retrieve more accurate soundings and to assimilate these data into models that were designed to accept synoptic measurements. Introducing asynoptic satellite observations "shocked" the models and caused other problems in the numerical stability of the computations as well. These problems have been virtually eliminated now. We have even developed techniques to remove the contamination of the temperature sounding by clouds, water vapor, unwanted minor constituents, aerosols, etc. Most important, we have demonstrated that adding satellite-derived temperature soundings and winds significantly improves mid-range weather forecast accuracy (3 - 10 days).

You may recall the Global Atmospheric Research Program's (GARP) Global Weather Experiment which was conducted in 1978-79. It involved over 140 countries, cost \$300 million, and provided us with the most complete set of observations of the atmosphere ever made. The experiment used five geosynchronous satellites, two polar orbiters and a multitude of special ships, buoys, drifting superpressure balloons and aircraft observing systems. We are intensively investigating this data set to discover the limits of predictability and to define the optimum global observing system we need. We, in NASA, are spending over \$7 million per year to support this research which is being done

with strong participation by the academic community. In addition, we have made a substantial commitment to the analysis of satellite data and the development of improved models of the atmosphere by acquiring a new vector processor, the Cyber 205. This machine and its attendant systems comprise a computing facility which will have a speed of over 100 million instructions per second, and an on-line memory of 110 billion words. We anticipate that this ten-fold increase in computing power will enable us to run models that were simply too long and costly to run previously. These models will have more realistic physics formulated in them and will have much higher vertical and horizontal resolution as well.

We have already learned a great deal from our work with the Global Weather Experiment data sets. For example, we have shown that: satellite observations positively impact the range and accuracy of weather forecasts; tropical observations must be included in 3-4 day forecasts at mid-latitudes; the current conventional upper air observing system is inadequate for even 6-hour forecasts except over North American and Eurasia; and we have discovered several new aspects of the South Hemisphere circulation that we didn't know existed (standing Rossby waves, and a more intense circumpolar frontal circulation than the North Hemisphere counterpart).

With the launch of GOES-4, temperature soundings from geosynchronous altitudes became a reality. The NASA-developed VAS (VISSR Atmospheric Sounder) instrument which uses the infrared emission of the atmosphere to sense temperature and water vapor permits us to observe the time evolution of convective storms in detail. These kinds of data will hopefully lead to improved detection and short-term forecasts of thunderstorms and tornadic activity. It is important to note that for atmospheric phenomena which occur on the temporal and spatial scales involved in thunderstorms, space observations (used together with ground-based measurements) offer the only economically viable approach to obtaining not only the repeated coverage needed, but also the dense grid of observations, as well.

There is one other area of satellite applications to aviation I wish to mention. You are probably familiar with the location and tracking of mobile platforms capabilities available from satellites. This technique, which was developed by NASA on the early Nimbus satellites, has now been adopted operationally by NOAA on the TIROS-N class spacecraft and even by the U.S.S.R. This system can be an invaluable aid to airmen in distress. For example, in 1977, there were 4286 aircraft crashes with 1440 of these requiring a search. In 1978, the U. S. Coast Guard responded to 3348 calls for aid in areas 25 or more miles from shore. Rescue is vital to survival of crash victims, and over half can be saved if they are rescued within 8 hours. Emergency transmitters are installed in 200,000 U. S. civil aircraft and 6,000 vessels. Sarsat (for search and rescue) will provide 10 - 20 or 2-5km location accuracy depending on frequency

used, and can handle up to 10 simultaneous transmissions. Spacecraft will be launched in the February 1983 time frame and begin a joint demonstration with COSPAR (Committee on Space Research) in September 1983. The problem at present is that an U.S.S.R. satellite is receiving 15 - 20 reports each day from false alarms. Two rescues have been effected, but high false-alarm rate precludes use of the SAR (synthetic aperture radar) signal as an indicator. The planes/vessel must be listed as missing before a search is initiated. This could be costly to people who have an emergency.

The future for satellite applications to aviation looks very bright. Satellite instrumentation will contribute to better wind measurements, improved aircraft/ship routing, improved short-range and medium-range weather forecasting and better communications, including search and rescue capabilities.



# **SECTION V**

## **IMPROMPTU PRESENTATIONS**



**(FROM LEFT TO RIGHT)**

**JOE SHAW  
DAVID WINER  
NORM CRABILL  
WARREN CAMPBELL  
BOB MILLER  
COL. FARID CHEDE  
DAVID BURNHAM  
ALAN WOODFIELD  
DENNIS CAMP**

# A Cursory Glance at Results from NASA's B-57B Gust Gradient Program

Warren Campbell  
NASA/Marshall Space Flight Center

The Gust Gradient Program is summarized in Figure 1. An assumption frequently made in turbulence modeling is that there is no spanwise variation in turbulent gusts. If this assumption were true, an aircraft would not experience rolling and yawing moments. Some turbulence models do simulate gust gradients, but they are accounted for in a theoretical manner (based on Dryden, Von Karman, or other spectral models). These models are questionable at low altitudes in the planetary boundary layer. Virtually no spanwise gust gradient data have been published, and the purpose of the Gust Gradient Program is to fill this gap.

The third part of Figure 1 indicates how the aircraft was flown to obtain data. The B-57B normally will only be flown at locations provid-

ing weather radar and preferably Doppler radar. At these sites, it will take off when radar indicates a storm cell within roughly 20 nautical miles of the runway. Data is collected at takeoff and up to an altitude of about 1000m. At that point, the data recorder is shut off and the B-57B approaches the cell as closely as possible and executes a level flyby (where the recorder is again turned on) of the storm in the vicinity of outflows, turbulence, etc., if possible. The plane returns to the runway, executes a touch-and-go and returns to the storm at possibly a different altitude. This cycle continues until the storm cell moves outside a convenient radius, or until the data recorder runs out of magnetic tape. The B-57B endurance is roughly three (3) hours and the recorder holds an hour of tape.

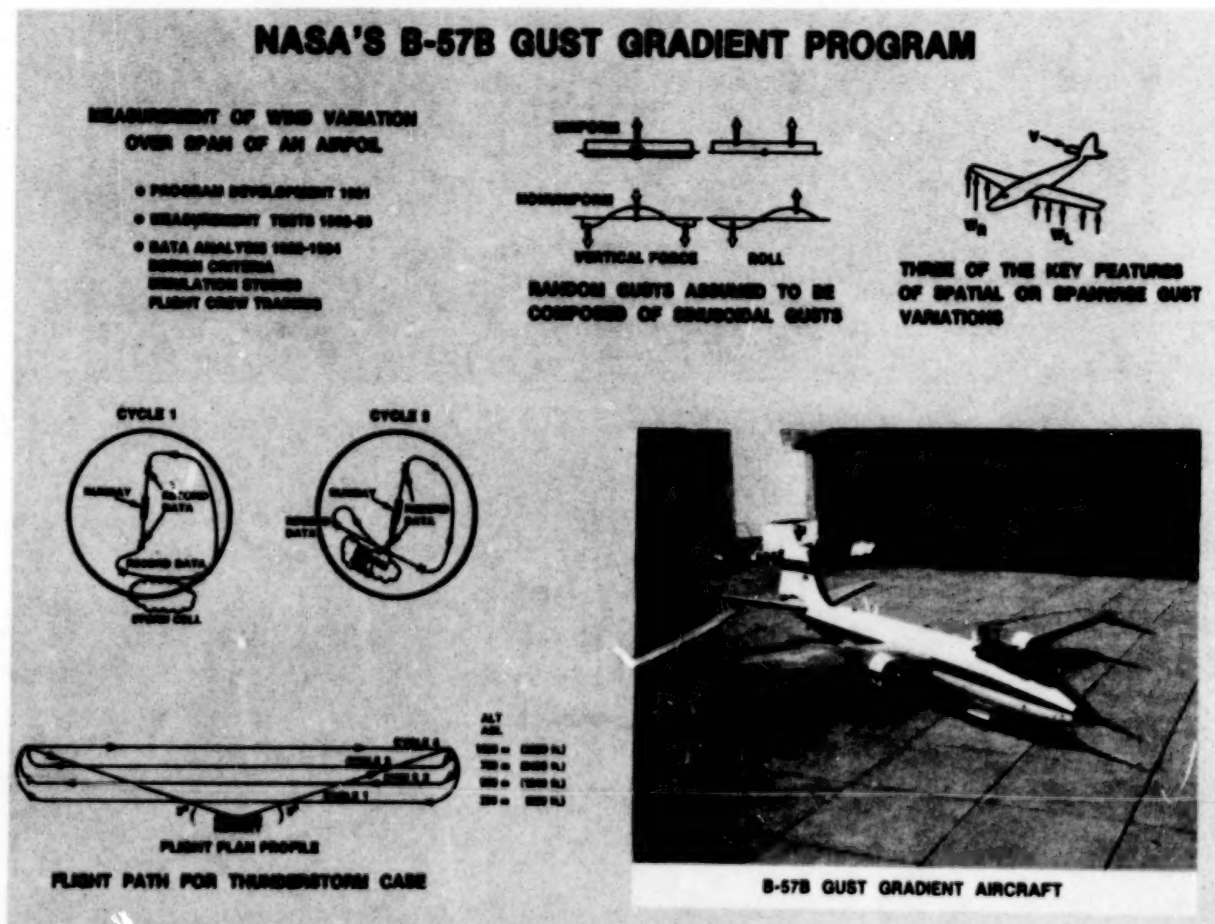


Figure 1. NASA B-57B Gust Gradient Program

Figure 2 shows possible locations for gust gradient flights. These locations include the four NASA Centers involved in the project. Langley Research Center (LaRC) is responsible for instrumentation on the aircraft and for converting voltage values on the data tapes to engineering units. Responsible individuals at LaRC include Hal Murrow and Robert Sleeper. Robert is attending this workshop. MSFC is responsible for data analysis. Responsible individuals at Marshall are Dennis Camp and myself. Dryden is responsible for all flight operations and the aircraft. The project manager at Dryden is Wen Painter. Wen is here at the workshop along with his wife, JoAnn, who helped us during the Joint Airport Weather Studies (JAWS) Project. Ames serves in an advisory capacity and also is responsible for one of the instruments on the aircraft, an IR radiometer. UTSI, through Walt Frost, has been very much involved in planning the overall program and in the data analyses. To date, data flights have been flown at LaRC (checkout), at Denver in conjunction with the JAWS Project and at Dryden. The only really complete data set is from Denver.

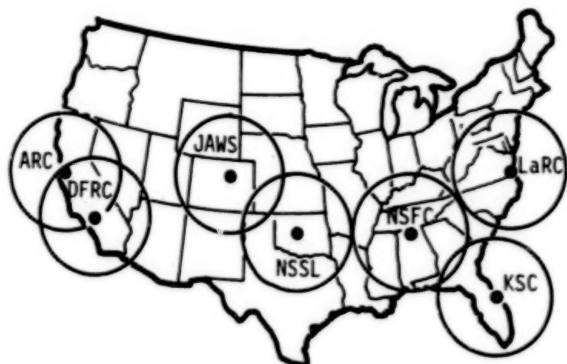


Figure 2. B-57B COVERAGE (100km AND 500km RADII)

The Gust Gradient Program moved to Denver this past summer (1982) from July 7 to July 23, to participate in the JAWS Project. This international program was a data intensive effort involving triple Doppler radar, a surface weather station mesonet and other aircraft. The JAWS area is shown in Figure 3. The center of flight

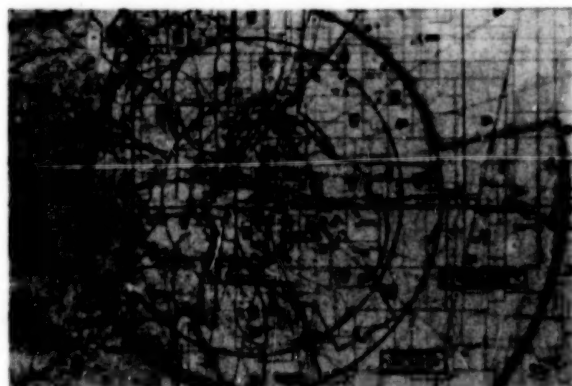


Figure 3. JAWS Area Map

activity was Stapleton airport. The other aircraft in the program flew out of Jeffco and the B-57B flew out of Buckley Air National Guard Base.

Figure 3 depicts the CP-2 site which was operational headquarters for the JAWS Project. Shown is the radome and several trailers, one of which is the operations van. The flight engineer (Dennis Camp or myself) was in the operations van during each test. The test engineer had access to a radar console which indicated weather conditions and aircraft locations. With help from JAWS Project radar meteorologists John McCarthy, Cathy Kessinger, Cindy Mueller or others, the engineer could direct the B-57B to "hot" locations. John and Cathy are attending this workshop.



Figure 4. JAWS Operations Center at CP-2

We were extremely fortunate during JAWS in the amount of good nasty weather that occurred. During our time at JAWS, rain, gustfronts, microbursts, tornadoes, funnel clouds and hail occurred within the JAWS network. On July 14, a funnel cloud was sighted at CP-2. Another day, centimeter size hail fell at CP-2 and the noise inside the trailer was enough to disrupt communications with the aircraft.

During JAWS, eleven (11) different flights were made. The test summary is indicated on Figure 5. The B-57B encountered severe turbulence on the three (3) flights of July 14, 15 and 21. The data analysis effort is currently concentrating on these severe cases. Of above-average interest, is Flight 3 on July 9, when the B-57B flew inter-comparison tests with the Royal Aircraft Establishment (UK) HS-125 aircraft, and the University of Wyoming King Air. Heading the RAE program is Alan Woodfield who is here and Wayne Sand, also here, piloted the King Air.

<u>FLIGHT</u>	<u>DATE</u>	<u>START</u>	<u>END</u>	<u>COMMENTS</u>
1	7/7	15:41:38	15:59:39	Landmark Familiarization Flight
2	7/8	14:49:11	16:40:35	Light to Moderate Turbulence
3	7/9	13:17:10	15:42:34	Light to Moderate Turbulence with Data Correlation with JAWS 02 and 03
4	7/11	14:46:07	17:02:44	Moderate Turbulence and Lightning
5	7/13	15:20:18	16:44:56	ILS Approaches to Stapleton in Light Turbulence
6	7/14	13:41:13	15:55:21	Severe Turbulence and Outflows Visible on Radar
7	7/15	14:08:13	16:26:20	Outflows, Severe Turbulence, and ILS Approaches
8	7/17	15:49:35	17:17:56	Rain with Light to Moderate Turbulence
9	7/20	15:59:30	18:35:52	Light to Moderate Turbulence with some ILS Approaches
10	7/21	16:05:05	18:04:40	Good Downburst with Moderate to Severe Turbulence
11	7/22	13:36:09	15:24:45	Light and Moderate Turbulence

Figure 5. Gust Gradient Flight During JAWS 1982

Some data from two (2) runs occurring during Flight 7 (July 15) is presented in Figures 6 - 15. Figures 6 - 9 show the altitude traces for Runs 11 - 14. Two of these tests were level flights and two were simulated ILS approaches over open fields. The minimum ordinate is 1.5 km above sea level which is roughly ground level in the Denver area.

Figure 10 shows true airspeed for Run 10 (a straight and level flight). Several sudden rises and drops in airspeed are indicated on this figure which could result from outflow features.

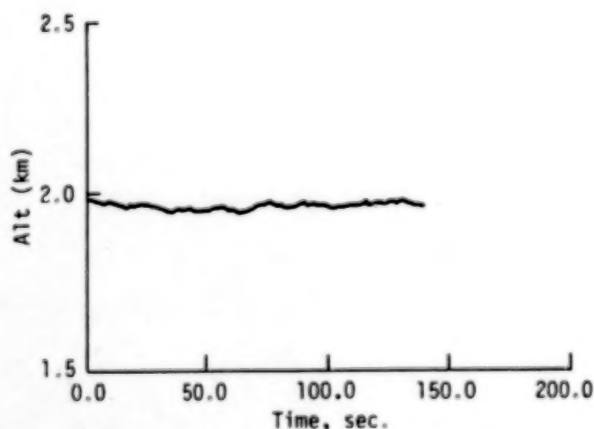


Figure 6. Altitude Trace for Run 11.

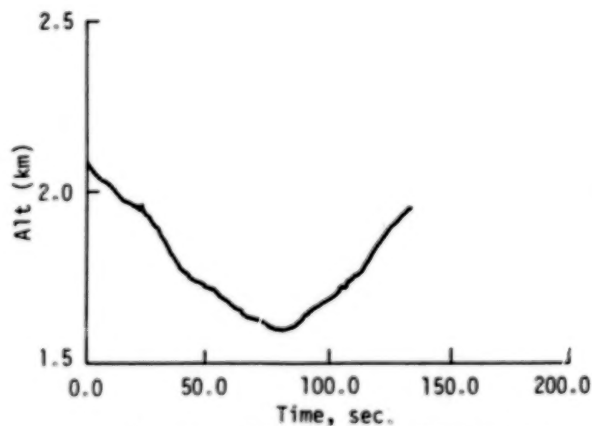


Figure 7. Altitude Trace for Run 12.

Figures 11 and 12 are traces of turbulent velocity measured at the center and right wingtip booms. When overlaid, it can be seen that these traces are very similar, especially in large-scale features. Intuitively, features of a scale larger than the 19.5m (60 ft.) wingspan of the B-57B should show up, simultaneously, in both velocity traces. Smaller scale features contributed to the differences in the two traces. From these two figures, some question arises as

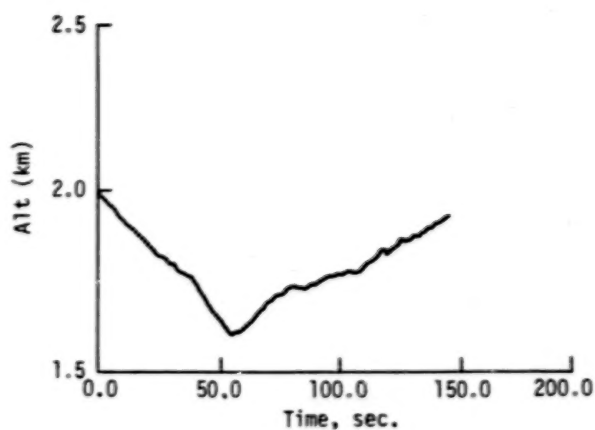


Figure 8. Altitude Trace for Run 13.

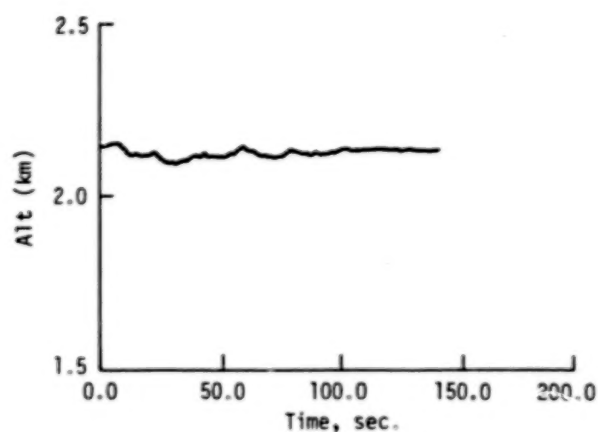


Figure 9. Altitude Trace for Run 14.

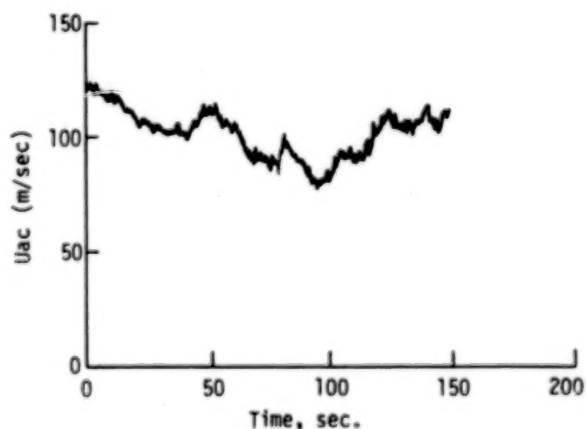


Figure 10. True Airspeed for Run 10.

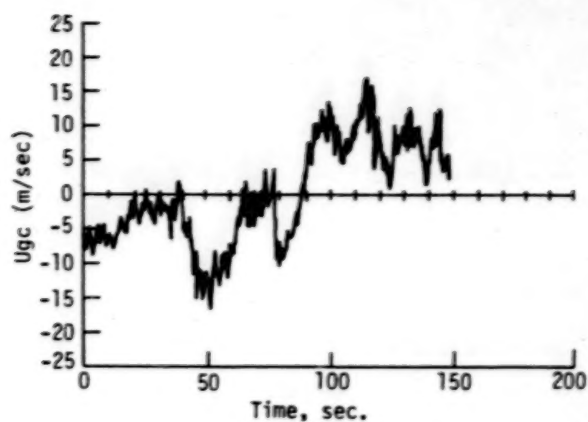


Figure 11. Ugc for Run 10.

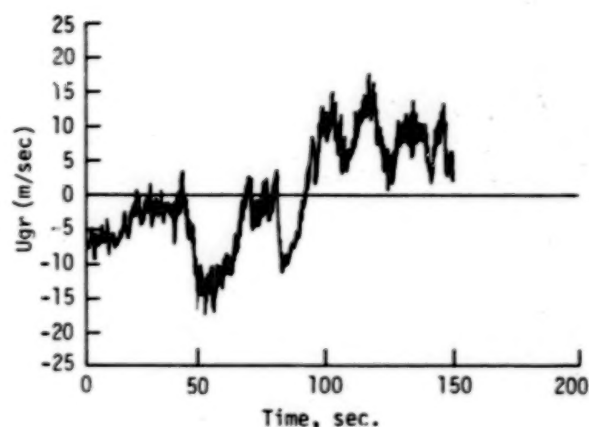


Figure 12. Ugr for Run 10.

to whether or not significant velocity changes occur across the wingspan. Figures 13 - 15 indicate that significant gradients do occur.

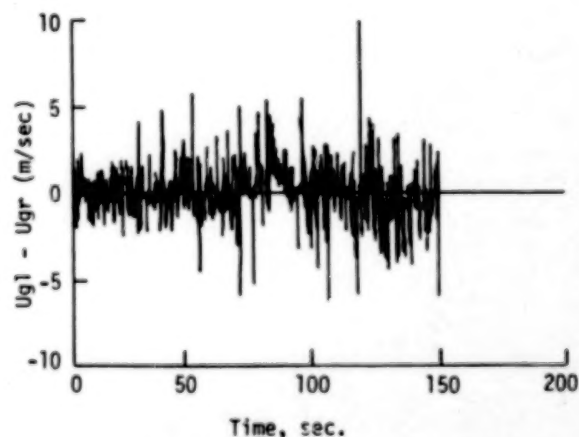


Figure 13. Ugl - Ugr for Run 10.



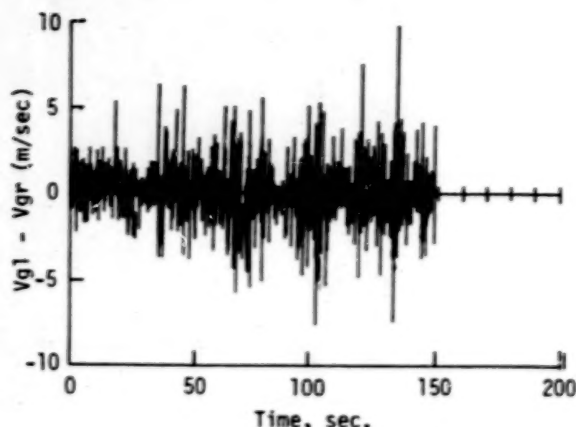


Figure 14.  $V_{g1} - V_{gr}$  for Run 10.

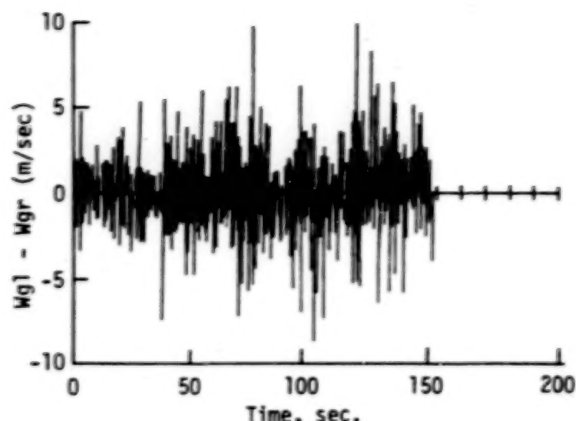


Figure 15.  $W_{g1} - W_{gr}$  for Run 10.

The last three (3) figures show differences in the longitudinal, lateral and vertical components of velocity. Note the peak velocity differences are 10 m/sec (20 kts) which is quite significant. During these runs, large values (up to  $12^\circ$ ) of roll attitudes occurred presumably because of these gradients. Another interesting feature of these figures is the filtering effect of the

differencing. Differencing removes large-scale variations which makes a large difference in the probability distributions. While individual velocities have a ragged, multimodal appearance, the densities for the velocity differences have an almost Gaussian appearance.

This concludes my presentation.

## GEM: Statistical Weather Forecasting Procedure

Robert G. Miller

The objective of the GEM Program was to develop a weather forecast guidance system that would:

- (1) predict between 0 - 6 hours all elements in the airways observations, that includes: ceiling; visibility; temperature; wind; present weather (such as fog); etc.;
- (2) respond instantly to the latest observed conditions of the surface weather, be they special or record observations;
- (3) process these observations at local sites on mini-computing equipment, such as the AFOS system;
- (4) exceed the accuracy of current persistence predictions at the shortest prediction of one hour and beyond;
- (5) exceed the accuracy of current forecast model output statistics inside eight hours; and
- (6) be capable of making predictions at one locations for all locations where weather information is available.

GEM, an acronym for Generalized Exponential Markov, fulfills all of these requirements and has the following additional features. It needs only the information contained in the airways

observation and requires no model output or surrounding station data; it is a generalized procedure, meaning it can predict anywhere, at any time and for any projection. Also, it can run on anything from a small, hand-held micro-computer such as the TRS-80 on up to the larger models. Since GEM was originally designed to handle observational information at non-standard times and at random locations, it is capable of utilizing observations such as PIREPs.

I would like to now explain about the creation of GEM. There are 41 stations from which data were taken. These are shown in Figure 1 with filled-in circles. The empty circles are the verification stations. Each of the filled-in stations contributed 100,000 observations to a statistical sample totaling 4,100,000. All elements in the observation were included as predictors and predictands. Transformations were made on the original observations producing 290 on/off conditions, yielding over 1 billion bits; and this was reduced to a matrix of 50,000 multivariate regression coefficients from which forecasts were then made. The matrix is used to make a forecast for one hour. This forecast, represented by probabilities of these 290 elements, is fed back as the observation for the second iteration, and this process continues hour by hour until it finally settles down to climatology at some future projection, typically

around 24 hours or more. To make the forecast station specific, a simple additive constant is introduced that accounts for the local hourly and monthly climatologies. It has been found by exhaustive experimentation that the equations, themselves, are applicable anywhere. An exponential dampening is imposed to accommodate the continuous time Markov process.



Figure 1. Locations from which composite data were sampled. Filled circles represent the dependent sample stations; while open circles, the independent sample.

Figure 2 shows an example of what a forecast looks like. This is for March 21, 1980. The observation was taken at 7:00 local time for Washington, DC, and its airways observation is indicated on the first row. The temperature was 62° and this represents the mid-point of a five-degree interval. The dew-point depression was 1° and the visibility was six miles, light rain and fog were occurring with the wind direction 170° at 15 knots and so forth. The figure shows also the first and second cloud layers plus the total sky and the ceiling in hundreds of feet. The forecast of the same airways observation is made for three hours, six hours, nine hours and twelve hours. The forecasts for intermediate hours could have been produced, but GEM is limited to 7,000 bytes of the AFOS system with AFOS running. It is interesting to note that the case shown on Figure 2 had a frontal passage around 3100; and, as you can see, the change in the weather characteristics was indicated beginning with light rain showers, a wind shift and the intensification of the wind speed.

In terms of the verification of this system on the seven stations in Figure 1, amounting to about 24,000 independent observations, GEM predictions compared against persistence were more accurate, even beginning with the first hour. Anyone who has tried to improve upon persistence at one hour, knows that it is a difficult thing to accomplish. This was judged by analyzing the probabilities and the correct

<pre> GGG EEEEE N  N G      C      MN MN G CCG EEE  N  N G  G E      N  N GGG EEEEE N  N </pre>												
<p style="text-align: center;">TECHNIQUES DEVELOPMENT LABORATORY FOR STATION: DCA VALID FOR 12 HOURS AFTER MAR 21, 7 LOCAL</p>												
HOURL	TT	DPD	UU	WEATHER	DOFF	PPP	CI	H1	C2	H2	TS	CIG
7	62	1	0600	R- F	1715	9976	BKN	7	OVC	10	OVC	7
10	62	1	0600	R- F	1715	9976	OVC	5	OVC	10	OVC	7
13	62	1	0600	R- F	2615	9976	OVC	5	OVC	10	OVC	7
16	62	3	0400	R- RW- F	2425	9976	OVC	5	OVC	10	OVC	7
19	57	3	0400	R- RW- F	2425	9976	OVC	5	OVC	15	OVC	7

Figure 2. Minicomputer printout of a sample GEM forecast for March 21, 1980, made at 7:00 A.M. EST for DCA.

number of forecasts of the two procedures, where persistence probabilities were conditioned on the current value of persistence. When compared with MOS, the results showed a cross-over of skill at about eight hours, favoring GEM early and MOS later. We have succeeded in showing that MOS and GEM can be blended together with a resulting increase in skill. Under a GEM-MOS blend, GEM would be inhibited

in its versatility to forecast at any hour. Separate sets of equations for the blending would be required to account for all differences between the hour of the day of the GEM input observation and the last available MOS forecast cycle model output time. Requiring this model output would inhibit GEM's versatility. Therefore, this GEM-MOS blend has just been done for experimental purposes.

The details of GEM and the verification results are included in NOAA Technical Report No. 28. Our current plans for GEM are to subject it to a rigorous automation of field operations and service (AFOS) field tests at selected stations. The objective is subsequent use throughout the National Weather Service as objective guidance to cover 0 - 8 hours. We see the principle potential of its application for aviation as part of a local monitoring and updating package on AFOS. In other words, when an observation comes in, the package forecasts whether the terminal forecast is out of bounds, according to the amendment criteria. If necessary, the package will update the forecast with the GEM forecast. It takes about seven seconds to make a forecast like the one shown here.

We expect that this will be integrated into the Aviation Route Forecast system in a unique manner. Specifically, we can provide the predicted airways observation for display and incorporation into the analysis, whether objective or subjective. It could be the basis for predictive capabilities in the automated observation system, AWOS, ALWOS and PROFS. Because of its generalized capabilities, GEM does not require a large historical sample nor a totality of elements. Any subset of these elements can be used. We feel ultimately that GEM will be the basis for the 0 - 6 hour automated terminal forecast.

#### Questions from the Floor

QUESTION: Do you foresee GEM as part of PROFS?

RESPONSE: Bob Miller

Yes, I went on a trip to Boulder and talked with people that I know are interested in such a versatile system as this.

QUESTION: Are they interested?

RESPONSE: Bob Miller

I would say that they are, but I have yet to have them ask me to come and design the set-up.

QUESTION: You said GEM predicted a frontal passage. How can it do that?

RESPONSE: Bob Miller

Don't ask me how, I don't know. It has gone beyond my wildest dreams. It has the ability to do things like begin precipitation, end it, or even change its type.

#### **REFERENCE**

1981 GEM: A Statistical Weather Forecasting Procedure. NOAA Technical Report NWS-28, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, 103 pp.

## **The PROFS FAA CWSU Support Evaluation Project**

John W. Hinkelman, Jr.  
FAA Rep to PROFS Program/  
Environmental Research Labs, NOAA

Eighteen months ago I briefed these proceedings on the PROFS Program and our plans and expectations. For those of you who are not familiar, PROFS stands for Prototype Regional Observing and Forecasting Service. PROFS is the top-priority NOAA Research and Development and Systems Integration Program. It is a local or user-scale program concentrating during its first phase on improving metropolitan area (aviation terminal area) services. We're utilizing the newest technologies in weather observation, data analysis and forecasting and information dissemination and integrating these activities together to provide more operationally oriented products to users. The latest capabilities in observations, objective data analysis and short period forecasting are being used concentrating during Phase I on very short-period severe thunderstorm prediction.

This past summer we utilized the NCAR CP-2 Doppler radar jointly with the JAWS Program, along with conventional weather service radars at Limon and Cheyenne, 21 automated observing stations which provide general coverage of the

Denver Terminal area and half hourly GOES satellite, visual and IR data. We've also incorporated information from an automatic upper-air sounder, the profiler, taking wind, temperature and humidity observations on a 20-minute basis. By 1983, we will have four profilers operating, covering the state of Colorado.

All of these data are processed in real-time at our Boulder facility on two VAX 780's, one 750 and four PDP 11/24's. Processed data are then displayed at our high-resolution RAMTEK display developmental forecast workstation for forecaster use in preparing operationally-oriented products. From time of ingest of our five-minute data sets to product output, takes less than two minutes. Current storm conditions, expected storm tracks and areas of anticipated severe weather are displayed and disseminated in real-time. We provide two outputs--one to the Denver Forecast Office for public use, and a subset to the Denver ARTCC's Center Weather Service Unit for aviation use. Our Forecast Workstation configuration is very similar to the planned FAA CWSU automated workstation to

be implemented in the 1985-87 period. Therefore, the PROFS CWSU system very appropriately can and is being used to operationally evaluate functional requirements and specifications for the planned FAA configuration.

I would like now to discuss with you some of the results of our summer 1982 evaluation program at the Denver ARTCC CWSU. In addition to real-time operational forecast evaluation, we tested color-display resolution, various background configurations, radar contouring techniques, radar and mesonet compositing, display looping, etc., and various display-menu-product call-up and user-oriented self-help schemes.

The Denver Center conducted an evaluation of the first three months of the program-- April 15 through July 15, 1982. During the 92-day period, significant weather occurred on 51 days. Sixteen key event-days were analyzed, three up-slope cases, with low ceiling and visibility where terminal capacity was impacted; two frontal passages where runway changes were forecast and implemented in a timely manner; three combined up-slope/thunderstorm situations; three ordinary thunderstorm events; and four severe storm cases. In two of the severe storm cases, Doppler radar information could have had a very positive impact. Radar cell tracking was very valuable. The mesonet data had a strong impact on quota-flow restrictions, particularly during up-slope conditions. The mesonet-radar combination was very useful. Mesonet data displays showed shearlines along which severe

thunderstorms actually developed.

The evaluation showed that: (1) radar is the single-most useful data source; (2) radar plus mesonet is the most useful overlay combination; (3) mesoscale sensitive objective analysis techniques (Barnes) are required in contrast to Cressman and other techniques that have been developed through the years, but are not adequate; (4) time series plots of surface and profiler information would have been very useful in the Center; (5) manual radar cell tracking was most useful but needs to be automated for 1983 use.

Additional PROFS products, including radar mosaics, satellite radar composites, automated surface mesonet analyses, Doppler radar data, etc., were available but program limitations prevented additional testing in 1982. The FAA has requested an expanded capability in 1983 for additional product testing and recommended that the facility at Longmont become a test bed for training other Center Weather Service Unit Meteorologists. Doppler radar product testing is planned with this expanded capability.

In summary, the PROFS/FAA Denver CWSU Product Evaluation Project has already provided significant, useful inputs to CWSU automation and the enhanced 1983 program with Doppler radar and additional profiler data inputs is expected to become an even more valuable asset to FAA weather program development activities.

## **Weather Concept From Cockpit**

Col. Farid Cezar Chede  
Brazilian Air Force, Retired  
Rio de Janeiro, Brazil

Every pilot-in-command knows that there is a big difference between the weather concept he gets from a Met office and the weather concept he gets on his own from the cockpit when he is flying.

In a Met office, for instance, a pilot-in-command is informed by the weatherman on duty that he is going to fly into a thunderstorm area. The pilot, of course, recognizes a thunderstorm when he sees one and he also knows what happens inside it. The pilot has also an idea that there are not two thunderstorms alike and that each thunderstorm has its own way of life and its own behavior.

The concept of the thunderstorm that the pilot has from the cockpit might not be the same concept given by the weatherman. This is because he can now make his own judgment from the details and aspects of the weather he can see and feel. He has to take procedures not according to the weatherman's (or Met Office's) concept of the thunderstorm, but according to

the details and aspects of the weather he can see from the cockpit and according to the effects he feels on the aircraft.

A pilot-in-command knows that every weather service in the world can only give him an idea of the weather he is going to encounter in flight. The real job of flying the weather, when he encounters it, is in his own hands. No one will be there to help him or tell him what to do.

The pilot has a good start by getting a weather concept from the point of view of a Met office but must depend on his own weather concept to take the correct action when actually flying in the weather. This weather concept from the cockpit will depend on his experience and on his meteorological background.

A pilot-in-command does not need a doctorate degree in Meteorology but he has to have a very good knowledge on the subject, which I call Operational Aeronautical Meteorology. I know



for sure that there are no books written about this subject. Even the ICAO Annex No. 1 does not address this subject; because, although ICAO does care about Met offices, it does not care about the feelings of a pilot-in-command flying through the weather.

It is important at this point of the lecture to explain the difference between these two weather concepts, which I have talked about. As everybody knows, a weather concept from the point of view of a Met office is simply the weather information a pilot is going to encounter in the air. This information will give him a very good idea of the weather he will encounter from take-off up to landing. The weather concept from the cockpit point of view is the real situation experienced in flight and the correct way to fly safely through it. The real situation might be different from those presented at the Met office. The pilot in the left seat can now see details and particular aspects that were not addressed by the weatherman at the Met office. The pilot now feels that he is on his own. He has to make his own judgment and make decisions based on what he sees and feels. This is not a fault of the weather service, it is just the fact that it is impossible to forecast all details and aspects of an individual atmospheric phenomenon.

The pilot has to estimate intensities; he has to judge the way the aircraft will interact with the atmosphere and above all, he must think about four basic principles:

1. How to recognize the weather as he flies toward it and how to judge it by details and particular aspects he can look for;
2. How to avoid it safely, if he has to;
3. How to take advantage of it, if possible;
4. How to survive it while at the same time adding more experience to his professional life.

Let me try to give an example of what I have just said. A pilot-in-command is taking off from an airport with thunderstorm activities throughout the area. He first acquires all weather information available and needed for the flight. This means that the pilot is getting a weather concept from the point of view of the Met office. Then he goes to the plane, takes the left seat and is now informed that there is wind shear over the aerodrome and over the active runway. In addition, heavy rain is pouring down all over the area. The low-level wind shear alert system has sounded and the controller warns the pilot of the wind shear danger. The

pilot thinks about all this, sums up his own experience and decides to take off. He will, of course, take all the recommended procedures for the particular situation as he evaluates it from the left seat. This is his concept of the weather from the cockpit.

The pilot now takes off. Two things might happen:

1. His weather concept from the cockpit was the right one. He considered all the factors and the successful take-off shows his experience was correct. He took all the correct procedures for the particular situation he was facing. He feels the aircraft respond to his commands and it rotates and lifts off safely.
2. He crashes one or two minutes after rotation. This means that his weather concept was not the right one. The pilot tried to consider all the factors but left out one or two critical ones and that was the end of all.

As everybody can see, and what experience has shown, is that the weather concept from the cockpit of a plane in the air is really vital for the pilot-in-command. The pilot has to have a very good knowledge of Operational Aeronautical Meteorology and his experience should be used in training other pilots for the benefit of flight safety.

Before I finish, I would like to bring up here a very interesting experience I had in Brazil. This was teaching and training pilots how to recognize weather in flight; how to avoid it; how to take advantage of it and most important, how to survive it, as opposed to teaching them the theory of meteorology.

I had a good reason to get involved in training because Brazil is an enormous country with almost continental dimensions and the Air Force Weather Branch is too small to provide weather support for the entire country. This is particularly true of the northern part covered by the Amazon jungle (around 4 million square miles), which has no facilities. Hundreds of small planes and helicopters fly everyday over the jungle and the pilots must be trained to find their own way through the equatorial weather.

I would like to conclude this lecture by suggesting that all pilots-in-command should be trained in Operational Aeronautical Meteorology, i.e., to obtain the right weather concept from the left seat. They should be taught much more about the interaction between the aircraft and the atmosphere and much less on meteorological theories that explain the general nature of weather phenomena.



## Current Status of Visibility Sensors for Aviation

David C. Burnham  
U. S. Department of Transportation

### INTRODUCTION

The visibility sensor that is currently used in the United States is, of course, the Transmissometer. It is normally installed on a 250-foot base line and will measure runway visual range (RVR) between 600 and 6,000 feet. There is a need to increase the range of those measurements to both lower and higher visibility for various purposes. In order to extend the RVR coverage to include Category IIIB, the range needs to be extended down to 100 feet RVR. This extension can be done with the current transmissometer by simply adding a second shorter base line (40 feet). Current transmissometer technology provides only a factor of ten dynamic range with a single base line. A second limitation of current transmissometers is that they are expensive to buy, install and maintain. A less costly instrument would be desirable.

The FAA is preparing to install automated weather observing systems (AWOS) at many locations in the United States, particularly smaller airports that have no observations at present. These systems require visibilities up to approximately five (5) miles. They don't need to measure low RVR (only down to 1/4 mile). In order to use a transmissometer for this type of measurement, the base line must be about 1,000 feet; where alignment becomes very difficult to maintain. Practical AWOS systems require high reliability, low maintenance and low cost. Consequently, a transmissometer is not the ideal instrument to be used for AWOS systems. Fortunately, over the last ten years, new technologies have been developed for measuring visibility. Improved transmissometers, forward-scatter meters and back-scatter meters have become available.

A current practical issue for visibility sensors is how to specify one that is good enough to meet the needs of aviation. No consensus has been reached concerning visibility sensor acceptance criteria. The first question is what performance is required; how accurately must the sensor measure? Visibility sensors do not actually measure the visibility directly; in fact, they measure the extinction coefficient which is then converted by standard equations into visibility. The purpose of measuring the visibility is to predict what the pilot will see a considerable distance away from the sensor location. Because the atmosphere introduces considerable variation in the measurement, the basic sensor accuracy needed is difficult to define. The second question for high visibilities is what to use as the standard reference sensor. For the visibilities currently being measured, the transmissometer is certainly a reasonable reference; but, for higher visibilities, it is not an easy reference to use. Several other options have been examined. A

third question pertains to the competitive procurement of visibility sensors, which is mandated at present. What acceptance test procedures should be used to insure satisfactory sensor performance?

### VISIBILITY SENSOR TECHNOLOGY

Three technologies are available for measuring visibility. The first is the conventional transmissometer; the second is the back-scatter meter; and the third is the forward-scatter meter.

The transmissometer has a primary virtue in that what it measures correlates most closely with what the human eye will see. The conventional transmissometer used in the United States suffers from a number of other problems, however. It is very sensitive to alignment and the window contamination. It must have a very narrow field of view in order to avoid systematic errors. It is also sensitive to background light because it uses a DC light level; and the windows must be cleaned often.

Recently we carried out some visibility sensor tests in the large climatic chamber at Eglin Air Force Base. The primary purpose of the tests was to evaluate sensor performance in dense Category IIIB fogs which are rare in nature. Of particular interest was the response of the current operational transmissometer, the Tasker RVR 500, on a 40-foot baseline. A variety of other transmissometers and forward-scatter meters were also tested.

The Europeans have developed a number of transmissometer systems that have a more advanced technology than what is used in the United States. One of these units is the Skopograph made by Impulsphysik in Germany. The projector uses a pulsed xenon flash lamp. Using the pulsed flash lamp eliminates background light problems. Otherwise, the Skopograph performance and costs are similar to the Tasker RVR 500. The Marconi MET-1 Transmissometer from England uses a very short baseline. Because the baseline is folded, the complete unit is slightly longer than three (3) meters and is installed on a single pedestal. The MET-1 includes precision light measurements and automatic calibrations in order to make a much more accurate measurement than in conventional transmissometers. As a result, a single MET-1 unit gives the same coverage achieved with a full dual-baseline system. Both the Skopograph and the MET-1 are used operationally in Europe.

A back-scatter meter called the Videograph is being used by the National Weather Service and the Coast Guard. It is also made by Impulsphysik in Germany. It is installed at a single

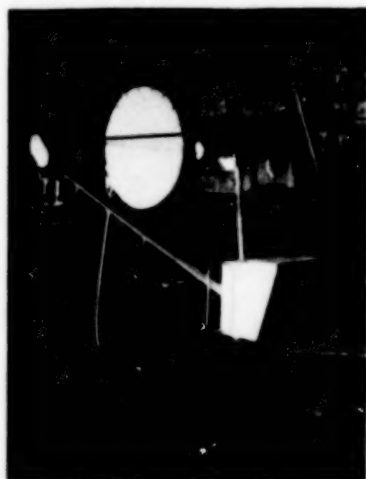


The Marconi MET-1 Transmissometer

point and transmits a narrow beam from a xenon flashlamp. A narrow receiver beam crosses the transmitted beam some distance away from the unit and looks for the back-scattered light. It averages over a reasonably large volume. The Videograph has developed into a good instrument in that it is stable and reliable. However, it has some calibration problems. The response to snow is much too large and cannot be corrected without a present-weather sensor. The response to haze is also too large, but it can probably be corrected with a relative humidity measurement.

A forward-scatter meter (FSM) looks at forward-scattered light rather than back-scattered light. The forward-scattered light has been shown to give a better correlation with the extinction coefficient for fog and snow than what is achieved with back-scattered light. Consequently, a FSM has a fundamental advantage over the back-scatter meter. On the other hand, at the present time, no forward-scatter meter has proven to be a reliable, stable instrument. All the existing units are either too new to have an established performance record or have well-known maintenance problems.

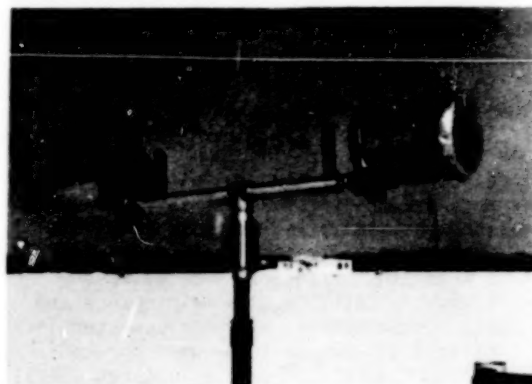
The EG&G 207 FSM has been used by the Air Force



EG&G 207 Forward-scatter Meter with Calibrator

for the last decade in a test environment. Its projector lamp sends out a cone of light with the middle blocked into the atmosphere. The receiver has the same type of beam, a cone with the middle blocked and looks at the scattered light from the ring where the two beams overlap. As the fog gets denser, the scattered light increases. Zero scattered light corresponds to very high visibility. In order to calibrate the EG&G 207 and tell if it responds in a fair visibility, a plastic scattering disc and a receiver attenuator are installed to check the response of the unit. The desired response to the calibration is determined by comparison with a transmissometer. An essential part of making the forward-scatter meter work is to have a calibration technique.

The Wright & Wright FOG-15 forward-scatter meter has virtually the same geometry as the EG&G, but is engineered to be simpler and easier to use. It is simply mounted to a post instead of a fancy tower like transmissometers because it is all self-contained.



Wright & Wright FOG-15 Forward-scatter Meter

Three other forward-scatter meters were also tested at Eglin. The Impulsephysik Fumosens-III is a downward-looking system that uses a pulsed flashlamp for its light source. The HSS VR-301 is a side-looking forward-scatter meter which uses a modulated LED as its light source. The Enertec EV-1000 is a side-looking forward-scatter meter made in France, which also uses a pulsed flashlamp. The EV-1000 scattering geometry was enclosed with light baffles which caused trouble in ice and snow. A more open geometry is needed for all-weather operation.

### TECHNICAL ISSUES

There are three technical issues which need further study. The first is the selection of a high visibility standard sensor. A 1000-foot baseline transmissometer can be used, but installation and maintenance are expensive. A laser transmissometer (the FAA owns 300 of them) may also serve as a long baseline standard. It worked well on shorter baselines in the Eglin



HHS VR-301 Forward-scatter Meter

tests. It may also be useful for high visibilities. A nephelometer may also play a useful role in making high visibility standard measurements.

The second issue has to do with the high visibility response of back-scatter and forward-scatter sensors which both show some nonlinearities. In other words, the signal is not necessarily proportional to the extinction coefficient. Figures 1 through 3 show some data measured in fog which illustrate this effect. The plots compare the forward-scatter meter response (extinction coefficient) to the transmissometer response. The calibration on the forward-scatter meter in Figure 1 is slightly off. If the two sensors agreed exactly, the data would lie on a diagonal line from corner to corner. The dashed lines represent errors of  $\pm 15$  percent. The solid diagonal line is the least-square fit to the data and is within a few percent of giving exact agreement between the sensors. The sensor agreement looks very reasonable on the scale of Figure 1. Figure 2 shows a factor of five increase in the scale. It is apparent that the data do not fit the straight line very well, especially at the lower values which seem to show a difference in slope.

Figure 3 shows another factor of five increase in scale and you can see that the slope is perhaps 50 percent different from the average slope of the data for fog. The high visibility region (low extinction coefficient) where the slope seems to be different corresponds to haze. One of the tasks that lies ahead is to develop a satisfactory nonlinear instrument calibration which will be satisfactory at high visibilities.

A third technical issue needing resolution is the question of whether an estimate of visibility produced by a point measurement of a forward-scatter meter is operationally compatible with the line average measurement of a transmissometer.

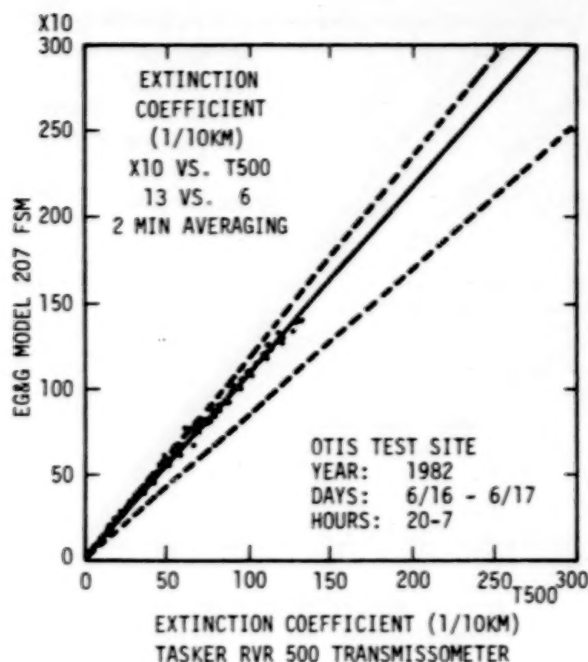


Figure 1. Scatter Plot Comparing a Forward-Scatter Meter Measurement to a 1000-foot Baseline Transmissometer Measurement.

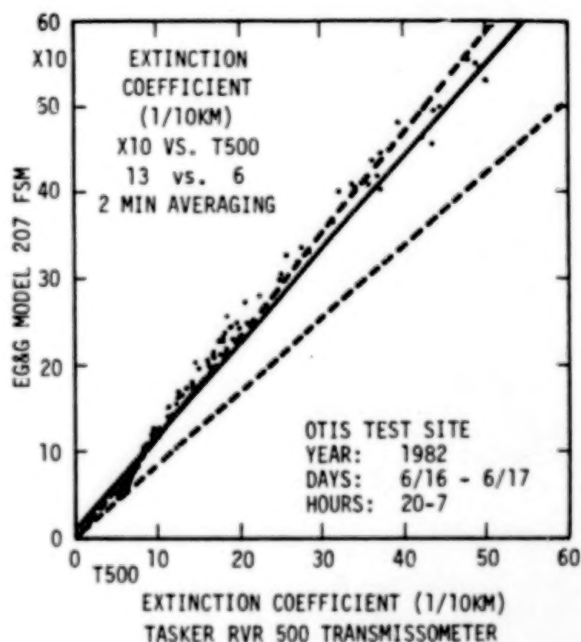


Figure 2. Figure 1 Expanded by a Factor of Five.

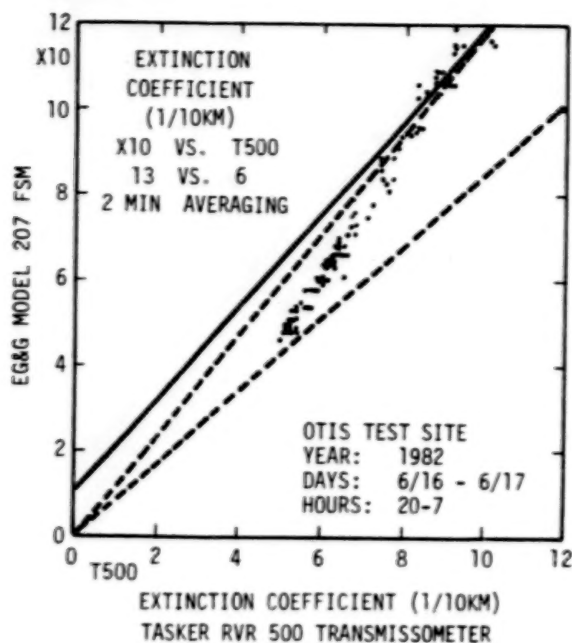


Figure 3. Figure 1 Expanded by a Factor of 25.

## The NASA Aircraft Icing Research Program

Robert J. Shaw  
NASA Lewis Research Center

The NASA Aircraft Icing Research Program has three major program elements as indicated in Figure 1. The major thrust of the program is to improve the understanding of the details of aircraft icing encounters for both fixed and rotary wing vehicles and how to minimize the impact of these encounters on aircraft safety. This requires a balanced research program which contains natural icing flight testing as well as more controlled simulation experiments. The simulation experiments can be conducted in ground or flight test facilities as well as by using computational fluid dynamics tools.

As Figure 1 attempts to indicate, it is extremely important to understand how the various simulation approaches relate to each other and most importantly to natural icing.

The following discussion will present some examples of NASA icing research currently being conducted within each of the three major program elements.

The aircraft icing problem is one which is ripe for the application of computational fluid dynamics tools. The NACA/NASA aircraft research effort was terminated before adequate computational capabilities were available, and thus that effect focused attention on experimental research in the NACA/NASA Icing Research Tunnel (IRT). In the succeeding years, various aerospace companies developed analytical tools for handling certain aspects of the icing problem, but these computer codes in general are not available in the open literature.

It is NASA's intention to develop a series of computer codes which will analyze various aspects of the icing problem, verify the accuracy of the code predictions by comparison with appropriate experimental data, and then make the codes available to the industry.

Figure 2 presents a list of the computer codes currently being developed. They fall into the areas of trajectory analysis, ice accretion analysis, aerodynamic performance degradation



and ice protection system performance. It is not meant to be implied that the computer codes currently being developed will treat all aspects of the icing problem; however, it is felt that these codes are the necessary building blocks from which additional analytical capabilities can be developed.

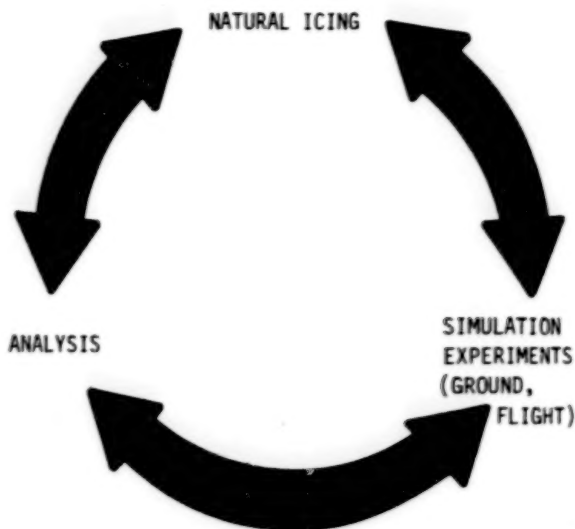


Figure 1. NASA Aircraft Icing Research Program Elements

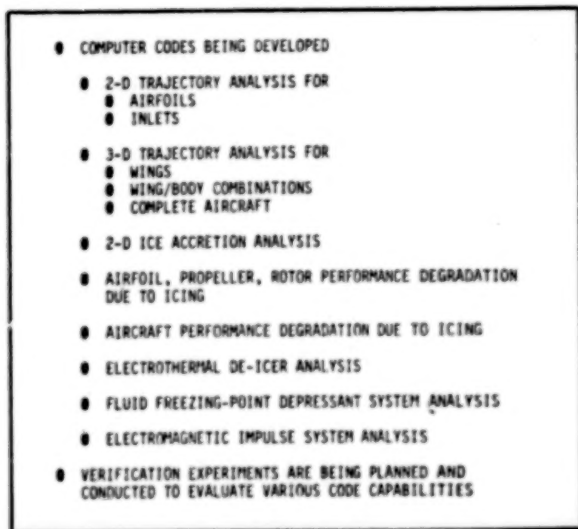
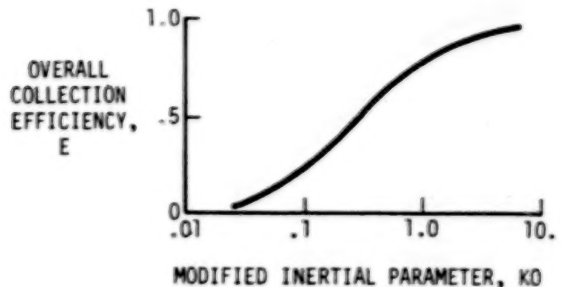


Figure 2. Computer Code Development and Verification

An example of the use of the aircraft icing analytical capabilities already developed is shown on Figure 3. The general aviation community indicated to NASA that the water drop collection efficiency information for general airfoil shapes available in the FAA ADS-4 document was insufficient since the airfoil de-

signs of interest today are often times significantly different from those studied by NACA icing researchers during the 1940-60 time period.

To satisfy this request, NASA funded a study at Ohio State University to perform a detailed set of collection efficiency calculations for some 30 airfoil sections which are of current interest. The calculations were performed with a water droplet, two-dimensional trajectory code. The accuracy of the code had already been estab-



- USE 2-D TRAJECTORY ANALYSIS CODE TO CALCULATE IMPINGEMENT LIMITS, COLLECTION EFFICIENCIES FOR 30 "MODERN" AIRFOILS FOR A VARIETY OF CONDITIONS.

- NACA 63 SERIES
- NACA 64 SERIES
- NACA 65 SERIES
- NACA 4 DIGIT SERIES
- NACA 5 DIGIT SERIES
- NASA LS SERIES
- NASA MS SERIES
- SUPERCritical
- EPPLER
- RECOMMENDED BY THE GENERAL AVIATION AIRCRAFT MANUFACTURERS

Figure 3. 2-D Airfoil Water Drop Collection Efficiency Calculations

lished by comparison of predictions with available experimental collection efficiency data. The results of the study will be published as a NASA Contractor Report.

A three-dimensional trajectory code has been developed which will predict water drop trajectories about complete aircraft configurations. The code is envisioned to have many uses; one of which is to aid in proper placement of icing instrumentation on aircraft. This code is currently being used to study the droplet trajectory characteristics about the NASA Twin Otter icing research aircraft (as Figure 4 shows) and to assist in interpreting the experimental results.

There appears to be an increased desire within the aircraft industry to use ice protection only



on those aircraft components for which ice accretion could seriously endanger the aircraft performance and stability/control characteristics. When a component is not protected, it is thus mandatory to determine the resulting aerodynamic performance degradation due to ice accretion.

The first step in gaining that understanding is to determine the ice accretion shape characteristics. This can be done either experimentally or by using computational techniques. Currently, no computational techniques exist to predict ice accretion characteristics for general air-

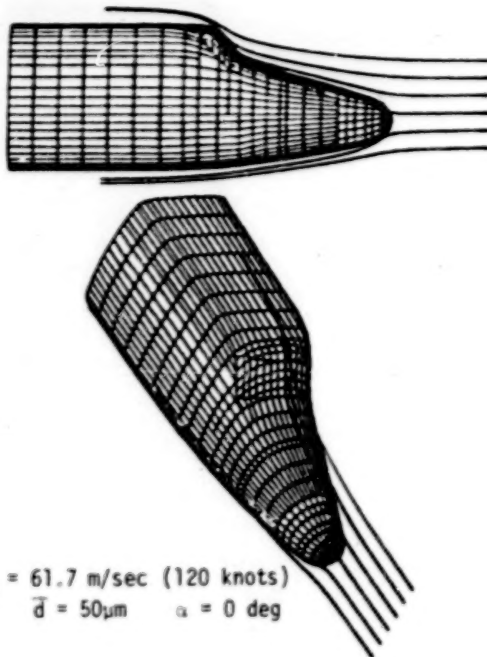


Figure 4. 3-D Trajectory Predictions Twin Otter Icing Aircraft

foil shapes. Rather the approach has been to correlate key ice accretion shape characteristics for the limited experimental data available for a few airfoil geometries as functions of known aerodynamic and environmental variables. The generality of these correlations is doubtful.

A more desirable approach is to develop a computer code which predicts ice accretion shapes based upon a solution of the governing energy equation for local water freezing rates. Such an airfoil ice accretion code is being developed by the University of Dayton and some preliminary code results are presented in Figure 5. While the two results shown indicate reasonable agreement between predicted and experimentally observed ice shapes, much work remains to be done before the ice accretion code accuracy has been verified. However, the long-term possibilities that such a code would possess make it an attractive alternate to existing experimental data correlations.

Once the ice accretion shape is known, the final and most important step is to predict the aerodynamic performance degradation due to that ice growth. Figure 6 indicates the currently demonstrated analytical capability to predict airfoil performance degradation with ice accretion shape. For this study, the Eppler airfoil code was used since it represents a state-of-the-art low speed airfoil analysis/design capability.

As Figure 6 indicates, the Eppler code predictions matched the experimental wind tunnel data for the clean airfoil which is to be expected. However, when the airfoil with the simulated rough rime ice shape was tested, the drag values measured significantly exceeded the levels pre-

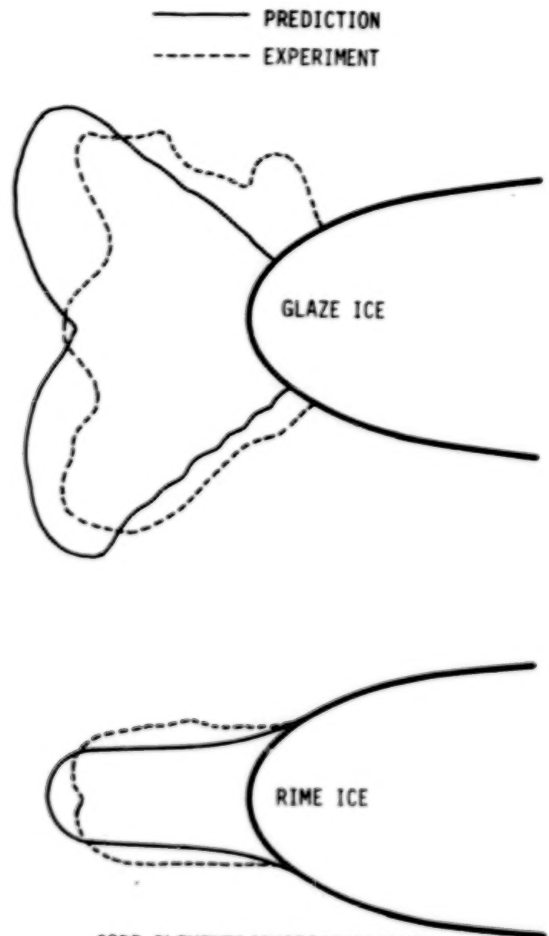


Figure 5. NASA Airfoil Ice Accretion Prediction Results

dicted by the original version of the Eppler code. In fact, it became necessary to modify the Eppler code predictions for drag by developing empirical correlations using existing icing wind tunnel data for drag increase on an airfoil caused by rime ice accretions. The resulting agreement is shown in Figure 6.

Currently, effort is underway to remove the need for the drag correlation by modifying the boundary layer calculational procedure to incorporate the effects of the rough surface texture of the rime ice growth on the boundary layer characteristics. It is felt that an inadequate modeling of the surface roughness effects is the major cause of the disagreement between theoretical predictions and experimental results.

EXPERIMENTAL: OSU 6 X 22 WIND TUNNEL  
ANALYTICAL: EPPLER AIRFOIL CODE

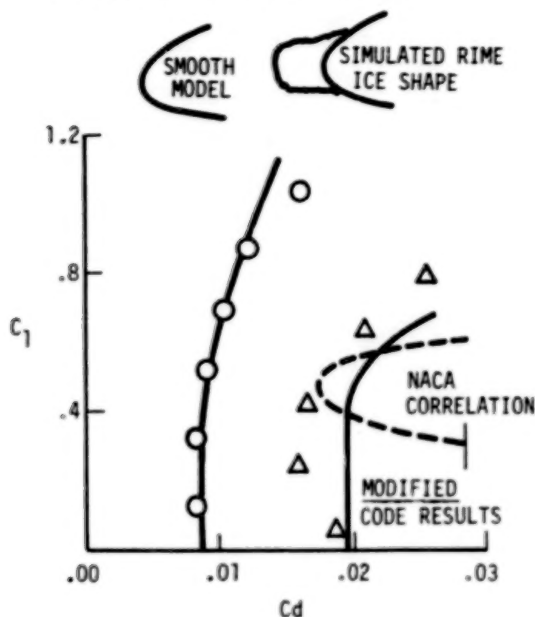


Figure 6. NACA 65A413 Airfoil Performance with Simulated Rime Ice

Work is also underway to develop analytical capabilities for predicting the details of the aerodynamic flowfield for the more serious glaze ice shapes. An adequate treatment of the glaze ice flowfield must include a treatment of the boundary layer separation-reattachment zone which can occur on either or both surfaces of the airfoil downstream of the ice accretion shape.

Figure 6 also shows the lift-drag polar predictions using the NACA performance correlations developed by NACA researchers. These correlations were developed from available experimental icing data for airfoils to give expressions for change in airfoil lift, drag and pitching moment due to ice accretion. The agreement for this particular case is not very good.

It is important to note that these performance correlations are still being used today to predict airfoil performance degradation due to ice accretions since no other correlations or analytical prediction capabilities currently exist.

Figure 7 shows comparisons for two general aviation airfoil sections tested in the NASA IRT of the experimentally measured drag increases due to icing with predictions made using the NACA correlation. Again, the scatter is seen to be large especially for the solid symbols which represent the high liquid water content data. However, with the exception of this high liquid water content data, the figure also indicates that the scatter in the results is no worse than the scatter for the original data upon which the correlation was based.

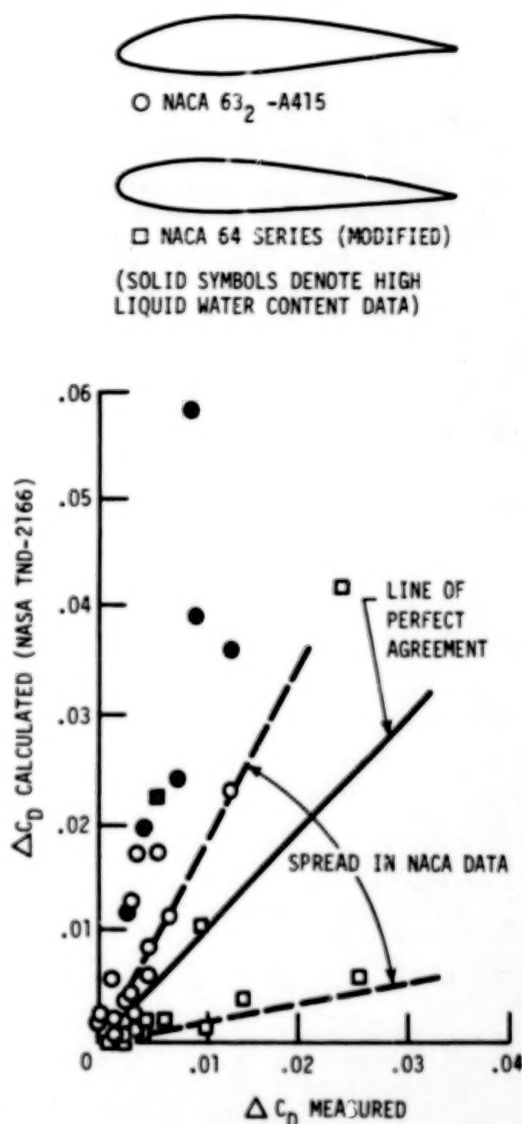


Figure 7. Predicted Drag vs. Measured Drag

Research efforts are continuing not only to develop analytical performance prediction techniques already mentioned, but to re-examine the correlation approach to see if more accurate correlations could be developed.

An ice protection system of great interest to sections of the aerospace community today is the electromagnetic impulse system. Figure 8 shows a closeup view of the leading edge of a wing section with the electromagnetic impulse system installed.

The electromagnetic impulse system employs a surface deflection approach to shedding the accreted ice. The heart of the system consists of a series of flat, spirally wound coils of wire shown in Figure 8 which are installed inside the leading edge. When a capacitor is discharged through the coil, the magnetic field of the coil induces eddy currents in the wing skin, causing it to deflect rapidly.

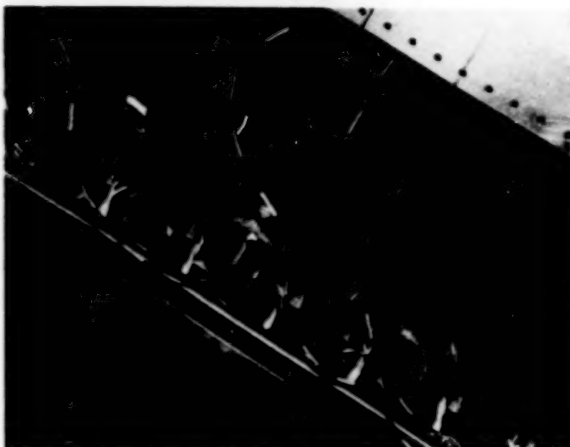


Figure 8. Closeup View of the Leading Edge of a Wing Section with the Electromagnetic Impulse System Installed

An electromagnetic impulse system for commercial transports was recently tested in the IRT in a joint Lewis/industry program. Data gained from that program is currently being analyzed.

Lewis has also assembled a NASA/university/industry team to develop the impulse system for both general aviation and commercial transport aircraft. Figure 9 shows the organization of this joint effort. The goal of this effort is to blend the talents and expertise of NASA, industry and university personnel to develop a fundamental data base for the electromagnetic impulse system which can be used by the aerospace industry for ice protection system selection and design.

Lewis has a joint program with the Air Force Flight Test Center (Edwards Air Force Base, California) to compare a number of old and modern icing cloud instruments using the IRT. The results to date of the study are summarized in Figure 10. The liquid water content indica-

ted by the instruments and compared with the IRT calibration varied by about  $\pm 20$  percent. A similar comparison for the drop size instruments indicated a variation of about  $\pm 4\mu\text{m}$ . It is felt that the scatter in the instrument results must be reduced, especially if the data is to be used in conjunction with computer code verification studies.

Since the NASA IRT has a maximum test section speed of 300 mph, ice accretion and aerodynamic performance degradation data for airfoils at high free stream velocities cannot be obtained in that facility. Such high speed data is required if the icing problems of the helicopter rotor are to be better understood.

In order to acquire such data, NASA has sponsored an eight-week test program in the Canadian National Research Council's (CNRC) high speed icing wind tunnel. The major tasks of the program are shown in Figure 11. The prime contractor on the effort, Sikorsky Aircraft, tested seven reduced scale (chord  $< 6$  inches) rotor geometries over a range of aerodynamic and environmental conditions for both fixed and oscillating angles-of-attack. The geometries selected are representative of current and future rotor airfoil sections.

As already indicated, a flight research program is a necessary part of a balanced aircraft icing research program. NASA initiated a flight icing program during the 1981-82 icing season using a Twin Otter aircraft shown in Figure 12. The objectives of the program are shown in Figure 13 with the two main goals being to provide data to verify the IRT and analytical simulations of the natural icing process.

Helicopter rotor icing presents some rather difficult icing problems many of which are not currently understood. To gain a better understanding of the rotor icing problem, NASA and the U. S. Army have initiated a Helicopter Icing Flight Test (HIFT) program. The major elements of the HIFT program are given in Figure 14. An unprotected UH1H helicopter will be flown behind the Canadian National Research Council's Ottawa spray and the main rotor system will be allowed to accrete ice. The helicopter will then be moved out of the cloud and rotor performance measurements will be taken. Once the helicopter has landed, detailed documentation of the rotor ice accretion characteristics will be undertaken.

The Ottawa spray rig test will be followed by dry transonic wind tunnel tests of UH1H rotor sections with artificial ice shapes which have been modeled using the ice shape documentation information obtained during the spray rig test.

The rotor section aerodynamic performance levels measured will then be used as inputs to an appropriate rotor performance code to predict the rotor aerodynamic performance with ice accretion and compare with the measured values.

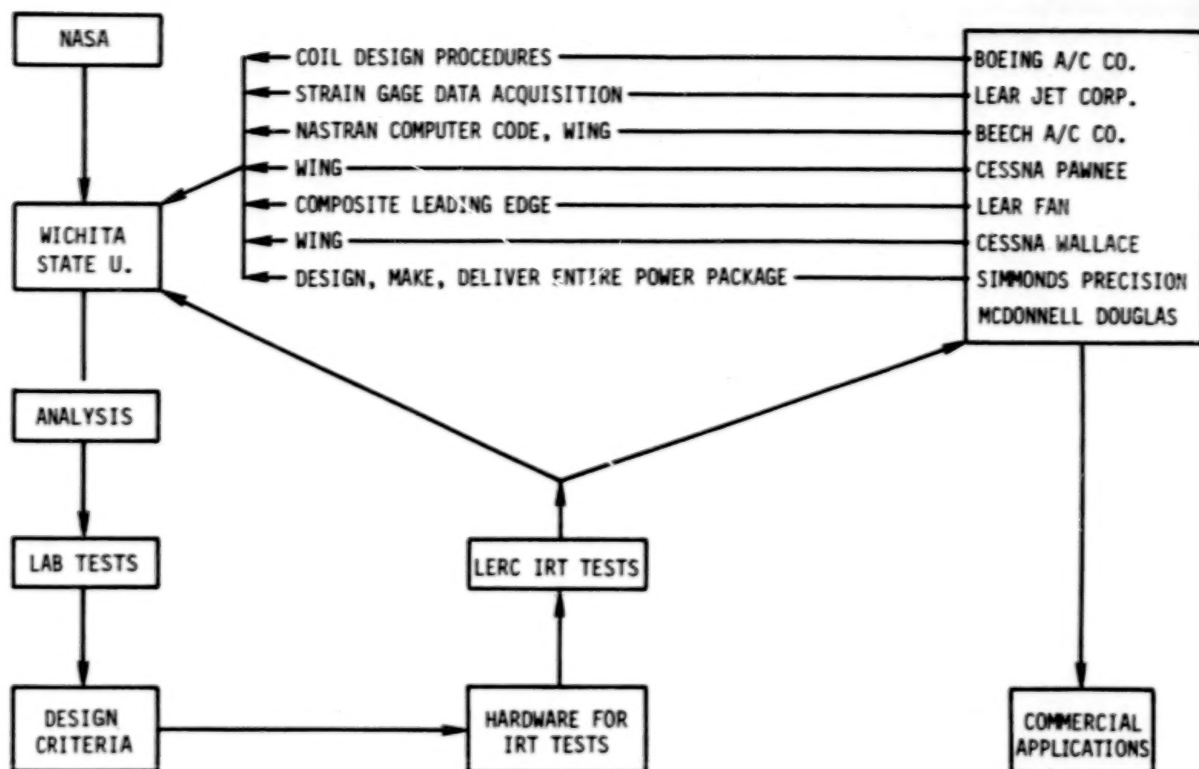


Figure 9. Electromagnetic Impulse De-Icing Joint Research Team

- MODERN AND OLD INSTRUMENTS WERE TESTED IN THE IRT
- SPREAD IN LWC INSTRUMENTS:  $\pm 20\%$
- SPREAD IN DROP SIZE INSTRUMENTS:  $\pm 4$  MICRONS

Figure 10. Icing Instrumentation Research Results

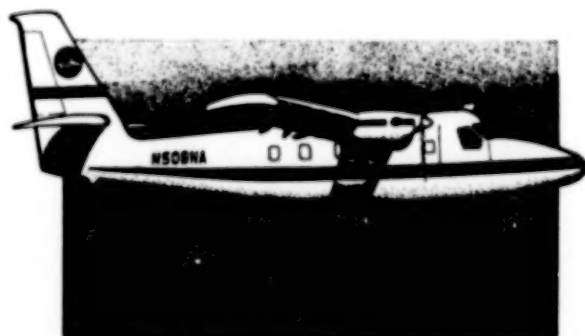


Figure 12. NASA Twin Otter Icing Research Aircraft

- TEST PROGRAM IN CANADIAN NRC 1' X 1' HIGH SPEED ICING WIND TUNNEL
- TEST REDUCED SCALE ( $C = 6"$ ) ROTOR AIRFOIL GEOMETRIES FOR FIXED AND OSCILLATING ANGLES-OF-ATTACK
- MEASURE ICE ACCRETION, AERODYNAMIC PERFORMANCE ( $\Delta C_L, \Delta C_D, \Delta C_m$ )
- CORRELATE PERFORMANCE MEASUREMENTS WITH AERODYNAMIC AND ENVIRONMENTAL VARIABLES, i.e.,  

$$\Delta C_L, \Delta C_D, \Delta C_m = f(V_\infty, \alpha, LWC, \bar{d}, T_\infty, E, E_{max}, r)$$
- TEST PROGRAM IN OXU 6 X 22 TRANSONIC WIND TUNNEL OF AIRFOILS WITH ARTIFICIAL ICE SHAPES TO MAKE DETAILED FLOW MEASUREMENTS AND COMPARE WITH NRC TEST RESULTS
- ROTOR PERFORMANCE DEGRADATION IN ICING CALCULATIONS AND COMPARISON WITH AVAILABLE ICING FLIGHT DATA

Figure 11. Airfoil High-Speed Ice Accretion, Aerodynamic Performance Studies



- PROVIDE DATA TO VERIFY ADEQUACY OF IRT SIMULATION
- PROVIDE DATA TO VERIFY COMPUTER CODE PREDICTIONS
- STUDY EFFECTS OF ICING ON AIRCRAFT PERFORMANCE, HANDLING CHARACTERISTICS
- PROVIDE ATMOSPHERIC ICING CLOUD DATA

Figure 13. Icing Flight Research Program Objectives

The NASA aircraft icing research program, some elements of which have been briefly described in this paper, is a broad-based program. The major goal of the program is to enhance the icing technology data base over that developed by former NACA and industry research efforts and to make this technology available to the industry in a timely manner.

- FLY AN UNPROTECTED UH1H HELICOPTER BEHIND CANADIAN NRC'S OTTAWA SPRAY RIG
- DETAILED DOCUMENTATION OF ROTOR ICE ACCRETION CHARACTERISTICS
- MEASUREMENT OF ROTOR PERFORMANCE DEGRADATION DUE TO ICING
- TESTS OF 2-D AIRFOIL MODELS WITH ARTIFICIAL ICE SHAPES TO DETERMINE  $C_{l}$ ,  $C_{d}$
- ANALYTICAL PREDICTIONS OF ROTOR PERFORMANCE IN ICING USING PERFORMANCE CODE AND EXPERIMENTAL 2-D AIRFOIL DATA
- COMPARISONS WITH FLIGHT DATA TO ASSESS METHODOLOGY

Figure 14. NASA/Army Helicopter Icing Flight Test Program

## Existing Wind Observation Network

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Office of Environment and Energy  
Federal Aviation Administration

There is an ambiguity in the title, "Existing Wind Observation Network". Before everyone rushes off for coffee, let me reassure you that I'm not going to talk about the balloon system. A better title would be, "A Real-Time Wind Observation Network". (Figure 1)

**"Real Time Wind Observation Network  
For Fuel Efficient Flight Planning  
and Air Traffic Control"**

Figure 1. Proposed Experimental System

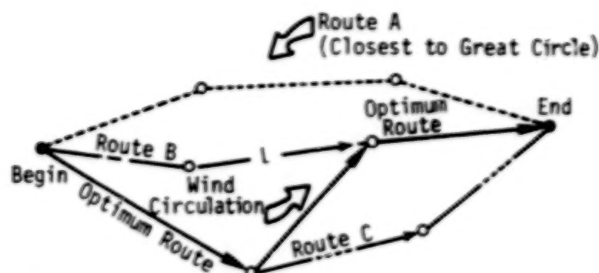
At the last workshop, our office presented a paper describing the need for better meteorological systems for fuel efficiency. We are an aviation energy organization, so that is our natural concern and perspective. Taking nothing away from safety concerns, we do believe that there is a woeful inattention in meteorology to the benefits that could accrue from fuel savings. So, we have turned our attention to this problem. The Energy Division figuratively backed into the subject of meteorology because we were developing flight planning programs that would be fuel efficient; and we soon found that you really cannot do much with high technology flight planning programs if you don't know what are the actual wind and temperature fields.

I would like to emphasize that this discussion is about a proposed system. It is for real-time wind observations and its purpose is fuel efficient flight planning and air traffic control. Let me show you an example of the kind of benefits that can accrue (Figure 2). Notice in this Figure, which was produced by the NASA/Lockheed TCV Program, that they investigated the possibilities of travelling several ways, including a great circle route, a more or less straight-line route, and following wind circulation patterns. It is interesting that the longest route actually uses the least fuel, some 14 percent less than the great circle route. This is an example of the kinds of fuel savings that are possible. I think this is an isolated example and probably not one you would expect routinely. To put this into perspective, just one percent of the air carrier fuel is 100 million gallons per year. So we think that improving the observation system has an enormous potential and probably could easily pay for itself in a year. That is, pay for itself in terms of reduced fuel bills.

The solution we see to the observation problem is the profiler instrumentation being developed at the NOAA/ERL/PROFS Program in Colorado. I need not go into the details of the program here. Some broad characteristics of the instrumentation and of the program can be seen in Figure 3. Importantly, the instrumentation can function in clear air as well as cloudy air.



Route	NMI	L 1011 LB Fuel	Excess Fuel
A	1620	47,500	+14.4%
B	1680	46,200	+11.3%
C	1785	43,700	+ 5.3%
Optimum	1810	41,500	Minimum



Source: NASA/Lockheed TCV Program  
June 81

Figure 2. Example of Route Optimization

- Profiler Provides Ground-Based Measurements of Upper Level Wind, Turbulence, Temperature and Moisture.
  - Long Wavelength VHF/UHF Doppler Radar with 3 Fixed Beam Directions, Large Fixed Antenna, 10 Minute Integration Time
  - Passive Microwave Radiometers Measure Temperature and Moisture Content
- "PROFS" Program Uses and Evaluates "State of the Art" Technology to Forecast Weather for Denver Area.
  - 4 or 5 Profilers + Surface Network + Weather Radars Connected in Real Time to Central Location.
  - One Profiler Operational, Remainder by Summer 1983.
  - PROFS Operationally Funded Until FY 88.
  - Data Link to Longmont ARTCC CWSU.

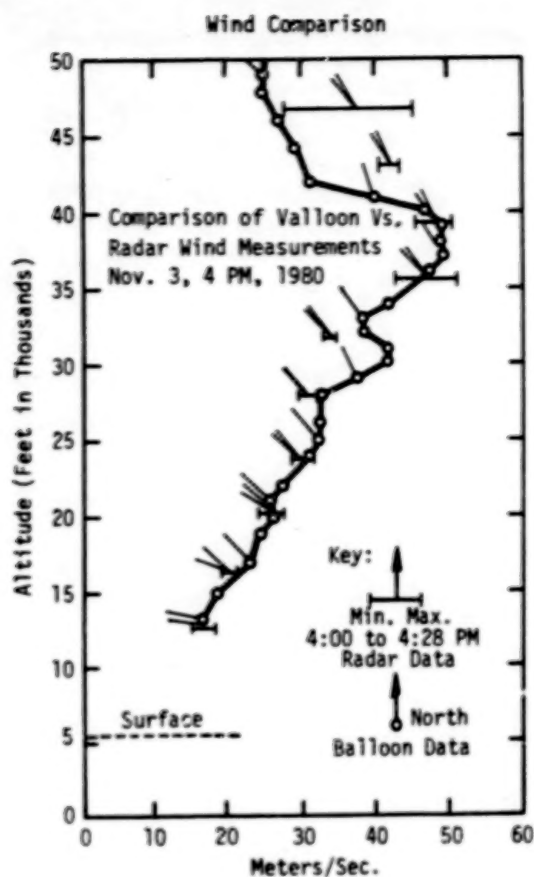
Figure 3. NOAA/ERL/PROFS Profiler

Figure 4 shows an example of the effectiveness of this new instrument system. I do not know whether or not the profiler always works this well; but these data at least indicate the type of accuracy available from the system. In this figure, the profiler data are plotted as accuracy bars of the wind velocity in meters per second versus altitude. The balloon measurements with which they are compared are shown as circles. Wind direction is shown in both sets of data as short lines relative to North. Notice that the profiler agrees with the balloon very nicely up to the higher altitudes, when and where the balloon is no longer overhead. You should expect to get quite a difference in this circumstance and you do. For temperature and vapor density, the profiler package can also do a good job. I have had people question whether this figure is a representative sample. At this time, I cannot answer the question, but expect to have much more information soon comparing the two systems. If this package is as accurate as indicated here, then it has the capability of replacing the balloon system.

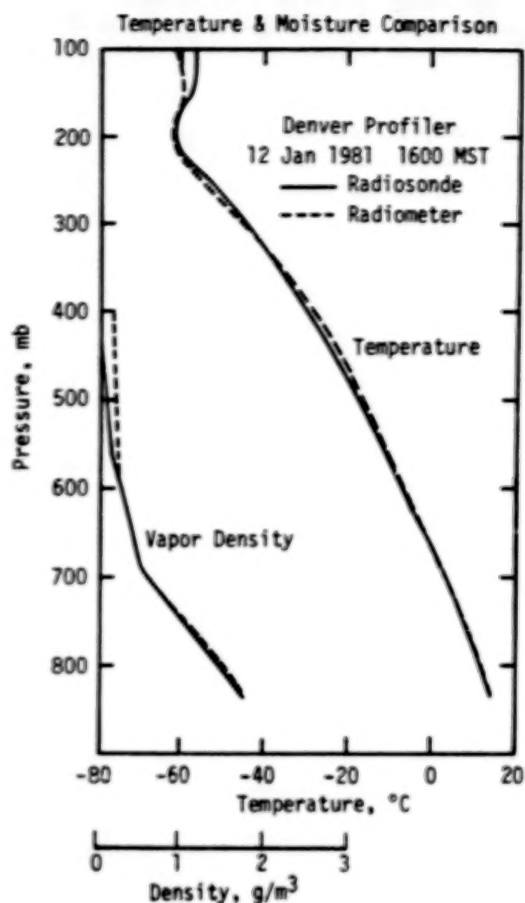
If the accuracy is comparable, why replace the balloon system? Some answers to this question are given in Figure 5. The time resolution for balloons...measurements every 12 hours...is totally inadequate for the kind of benefits that we really need for flight planning; that is, for route selection and optimum speed and altitude selection. It is also inadequate for proposed advanced air traffic control techniques and for flight management while airborne. As an example, if airborne computers were tied to computers on the ground that would reveal what the wind field is before making a descent, it would be a straight-forward matter to ensure a bottom of descent with an idle throttle from the beginning of descent.

Compared to other possible observation systems, balloons really do not offer a practical chance to improve much further. The future looks very promising for satellites; however, they are many years away as wind observing systems. Of course, we have existing systems of airplanes flying, from which wind fields can be estimated. Aircraft Meteorological Data Relay (AMDAR) and Aircraft/Satellite Data Relay (ASDAR), the Aeronautical Radio Incorporated Communications (ARINC) systems, are primarily used over oceans, although they could work over land. Mode-S is another airplane-type system from which ground computers could determine wind. However, in both of these cases, the distribution of wind information is not uniform in time and space. There is reason to doubt that such data could be used to calculate a reliable wind field database. The paramount advantage of the ground-based profiler system is continuous readings at all observing stations at all times.

We have envisioned a means of making this kind of real-time information available for use by everyone (Figure 6). Naturally, when people draw block diagrams, they tend to show their own interest as the largest block. The series of users at the bottom of this figure, for instance, could be depicted as large blocks in someone else's diagram. When storing this wind database in a computer, the publicly available data shown in the largest block in this diagram could reside inside of someone else's block. But the main idea is that wherever the data come from: Mode-S, AMDAR, these profilers, or in the far future, perhaps from satellites, it is important to store the observations themselves in one place. Give them a specified format of speed, direction, latitude and longitude, altitude and the temperature, if available...put these into a computer and give all users a telephone number and the format and let them pull out the data at will. Users would not have to read the whole thing. If one were interested in only a few locations, a program could extract these few data from a time-sharing port. To me, this is an essential feature that will encourage innovative use of wind data but will in no way preclude uses of further, more processed, products such as forecasts.



a.



b.

Figure 4. Profiler and Balloon Data Comparison



Figure 5.

In order to expedite this program, we would like to set up an experimental program. A general outline of such a system is shown in Figure 7. People are not going to be convinced that this could be a workable national system until they see some evidence. So, we are seeking to augment the existing plans for the four profilers in Colorado. Apparently, you cannot have a good talk unless you show a map of the United States with circles and dots, so here is ours in Figure 8. This shows the four locations in Colorado that are planned. We think that if six more were placed in a pattern between Denver and Chicago, this would provide enough of an experimental basis for flight planning and air traffic control use to establish very firmly whether or not such a system is beneficial. Actually, I do not think there is any question about whether or not it would be beneficial... it would be. However, it could be proven with a lot of objective experimental data. Also, with this kind of experiment, we can establish the engineering specifications for a national system.

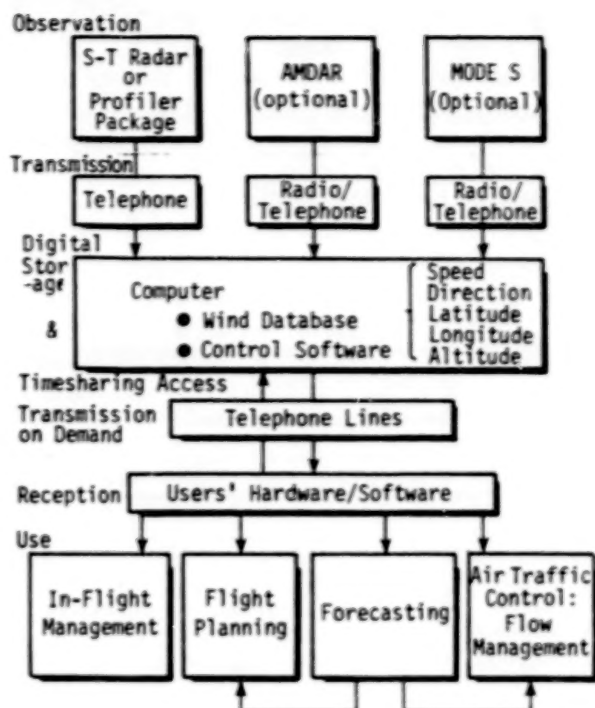


Figure 6. Proposed Wind Observation & Reporting System

- Establish Developmental Prototype System For Real Time Winds Aloft Computer Database
- Ground Based Sensors Report Wind Vectors at Cruise Altitudes
- Profiler and S-T Radar — Developmental Units to Be Installed and Operated By PROFS Program Office of NOAA ERL
- Sponsored Through Interagency Agreement — NOAA, FAA, NASA
- Wind and Temperature Measurements Transmitted to Central Database — Available on Demand to Flight Planners, Forecasters, ATC, Researchers, Etc.
- Target Date For Operational Prototype System — FY 84-85
- Airline Participation to Quantify Fuel Savings

Figure 7. Proposed Experimental Wind Observation Network

The functional specifications for profiler instruments are still in the early developmental stages. There are trade-offs that could be made in antenna size, and power, and frequency and so on; but if we're going to develop this particularly as an aviation system, we need to put some real-time observation instruments in place and work with them. These objectives are listed in Figure 9. Our office has recently entered into a contract with the PROFS office, in the form of an interagency agreement. We have asked PROFS to make a preliminary investigation of the specifications for aviation purposes. Also, we have asked that they document their estimates of the cost of the system and the benefits in fuel savings.

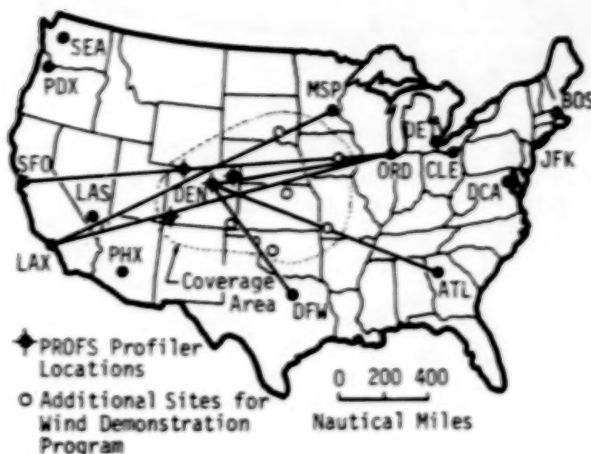


Figure 8. Possible Sensor Locations - Experimental Program

- Determine Utility of Using Real Time Wind Data For Flight Planning, Flow Management, And ATC Operations
- Obtain an Operational Data Base to Determine Fuel Saving Benefits of Real Time Wind Data System
- Establish Functional Specifications For Sensors — i.e., Frequency, Antenna, Power, Spacing, Etc.
- Establish Functional Specifications For Central Data Base

Figure 9. Experimental Objectives

Let's return to the subject of benefits. For flight planning, it is very important to know both the temperature and the wind field. Figure 10 illustrates the importance of knowing the wind field. One wants to get the best use of the tailwind or minimize the headwind. As a flight proceeds from place to place, it might pay in fuel saved to shift altitudes. Only with computers can you assimilate and use real-time wind data for optimum in-flight planning. Computer programs for this purpose are being developed. Our office is progressing on a model that we hope will tell exactly where to fly as well as what altitude and speed to fly to get the most out of the fuel. This technology is of limited value unless the computer is provided actual wind data. We really do not know what the upper winds are right now. Instead, we have forecasts, and these are of uncertain and varying quality.

Turning to air traffic control, there are also benefits (Figure 11). For integrated flow management, real-time winds would help to establish better routing. Air Traffic Control might wish to advise how to go around severe weather; but again, if they are to advise from a fuel-savings standpoint, their computers will

need to know what the winds are quite accurately. If ATC is to advise how to plan for the next few hours, they need better short-term wind projections than seem to be currently available. It seems obvious that if real-time wind information were available, short-term projections could be made more accurately. The en route automation program has a number of valuable uses for real-time wind as seen in Figure 11.

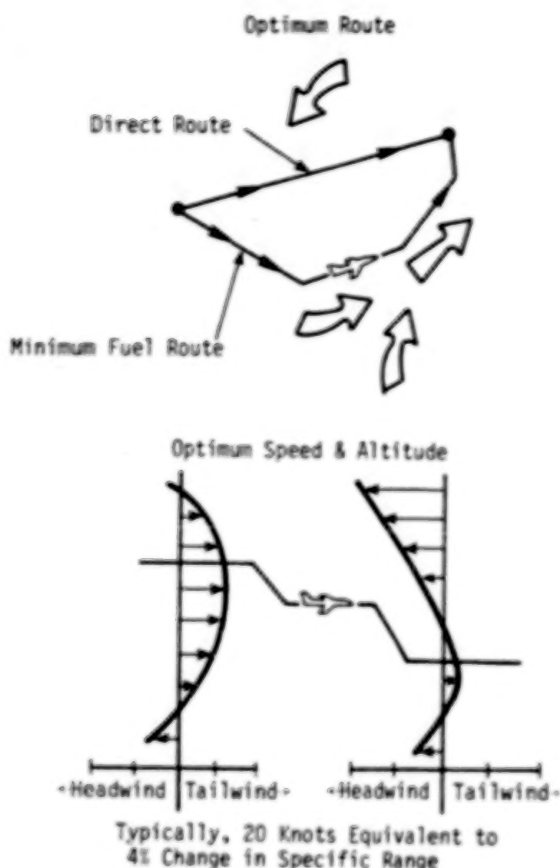


Figure 10. Flight Planning Benefits

#### • Flow Management (IFM)

- Optimal Routing
- Severe Weather Avoidance
- Predict Sector Utilization & Congestion Areas
- Develop Flow Management Strategies

#### • Enroute Automation (AERA)

- Improved Enroute Fix Accuracy
- Conflict Resolution
- Optimum Utilization of Random Routes
- Delay Management
- Descent Planning

Figure 11. Real-Time Upper Wind Data - ATC Benefits

Conflict resolution and estimates of arrival time over fixes can be improved for fuel efficiency purposes if ATC could sharpen the bell-shaped distribution curve of uncertainty. The tie-in to fuel conservation and system efficiency comes about from generally decreasing the uncertainty of exactly when an airplane will be at the next navigation point.

We conclude that the availability of widespread continuous real-time upper wind and temperature data will dramatically improve aviation efficiency, simultaneously helping both the users and managers of the airways. The NOAA/ERL/PROFS profiler instrument package appears to offer a near-term solution to the problem. Further development into a cost effective aviation system seems likely, but interagency and public support are needed to hasten introduction of an operational system.

#### Questions from the Floor

QUESTION: Andy Yates, United Airlines

A couple of comments: one, the fuel savings are generally accomplished over the long-range trips and not generally on shorter segments, by flight planning and using some of these winds. As an example, going from San Francisco to New York, you could achieve quite a bit of fuel savings over that range. But, going from Chicago to New York would not be that substantial. The other factor is that while we do have flight plans to give us the most economical or lowest fuel-use route, we can't fly it because the preferential routings which have been established by ATC in order to cope with the present traffic problems.

RESPONSE: David Winer

I've heard your last comment many times. Air traffic control is frequently being made out as the bug-a-bop in this problem. Regarding the first part of your comment about your flight planning program...there are really lots of ways to improve all the airline flight planning programs. Nobody really has the ultimate answer yet, although, I think United has one of the better ones. As far as ATC goes, I don't have the answer. If you would like to let ATC have a bigger hand in helping plan flights in the future, I think that could be done; but you're going to have to want that. Right now, we're in a current situation that is quite abnormal. I don't think we are in a position even to talk about doing the most fuel efficient things right now. We are struggling to stay afloat. But in the future with advanced systems, if the ATC can have a measure of control of the flight planning, at least a strength of recommendations greater than they have now, I think they can probably help you out of that problem.



# Marked Surface Inversions and Wind Shear- A Safety Risk for Departing Aircraft

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Marked surface inversions occur most frequently in dry continental climates, where low atmospheric humidity allows heat transfer by long wave thermal radiation. In the northern latitudes, surface inversions reach their maximum intensity during the winter, when the incoming sun's radiation is negligible and radiative cooling is dominant during the long nights. Also, during winter, air mass boundaries are sharp, which also favors formation of marked surface inversions. The existence of these inversions and sharp boundaries increase the risk of wind shear. According to ICAO, there is an operational requirement that pilots be informed, prior to departure, of any marked inversion in the lower levels of the atmosphere up to 1000 feet above ground level. The information should refer to marked inversions exceeding a temperature difference of  $10^{\circ}\text{C}$  up to 1000 feet. According to ICAO, there also exists a need to determine the temperature range over which the information is operationally needed and the magnitude of the inversion required before a notification to pilots prior to departure is warranted.

Near Helsinki airport, measurements are made with a 1000-foot high weathertower used in routine aviation service and for research purposes. Wind measurements are made at four (4) heights by anemometers equipped with IR-radiators to prevent icing. Temperature is measured at eight (8) heights with platinum-100 thermoelements. The statistics and cases presented in this paper were based on one-half hourly measurements made during the past four (4) years (1245 days).

Marked inversions occur mainly during winter months in Helsinki, see Figure 1. For example, during the observation period illustrated, 12 marked inversions occurred during December, which altogether lasted 74 hours. This is a three (3%) percent probability of the occurrence of such inversions. During January, the probability is nearly as high but decreases as spring advances. The absence of marked inversion during April may be explained by the humid conditions which exist due to melting snow. During this month, cyclone activity is also high, which means there is an advection of humid airmass from the Atlantic. During midsummer and autumn, no marked inversions occurred. This is because of the relatively warm sea in the summer, which normally freezes in winter.

The most probable time for an occurrence of a marked inversion is in winter (December - March). During the observation period, a marked inversion occurred on 23 days. This represents a six (6%) percent probability of occurrence of marked inversions, see Figure 2.

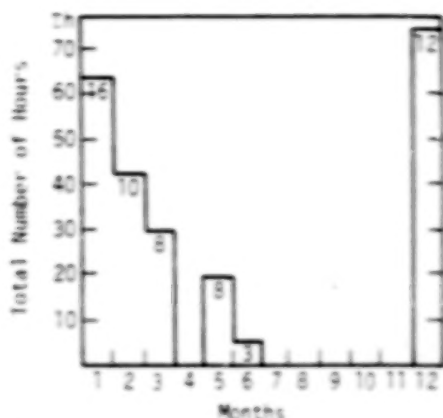


Figure 1. Monthly occurrence of marked inversions at Helsinki.

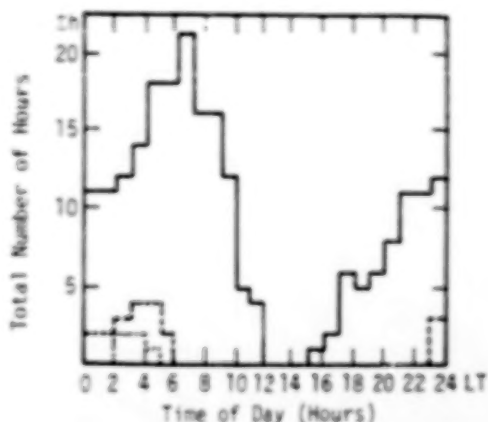


Figure 2. Hourly occurrence of marked inversions:

winter———;  
spring-----;  
summer.....

During the spring (April - May) marked inversions occurred only at midnight and early morning; and during the summer (June - September) inversions occurred only in the early morning. (Note that nights are extremely short during the summer.)

The strongest inversion detected during the total observational period, was  $\Delta T = 15^{\circ}\text{C}$  below 1000 feet (300 m), see Figure 3, profile 3. This inversion occurred in December. Profile 1 presents an extreme case of an inversion, in which the temperature rise occurs only above 100 m. This inversion took place in January during a warm advection. Profile 2 presents an extreme case, where the total temperature rise occurred in the lowest 20 m. This inversion was a radiation case in June.



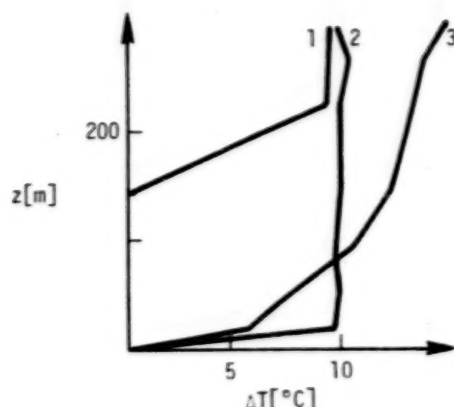


Figure 3. Examples of extreme cases, see text.

Table 1. Summary of marked inversion at Helsinki airport during the four-years observation period.

	winter	spring	summer	autumn
Surface temperature °C	-31 - -3	+1 - +9	+9 - +11	-
max. inversion °C/1000ft.	15	13	12	-
max. duration h	18	6	2	-
probability %	2.3	0.6	$0.7 \times 10^{-3}$	-
average height m	230	200	160	-

It is well known that air stability increases the risk of wind shear. It may not, however, be as widely known that wind shear also occurs during extremely stable conditions. Profile (a) in Figure 4 shows an increase in wind speed from 6 kt at 20 m to 24 kt at 90 m and a simultaneous wind direction change ( $\Delta\alpha$ ) of  $50^\circ$ . These conditions produce a wind shear magnitude of 9 kt/100 feet for the vector wind difference. For the case considered, the wind speed reaches a value of 34 kt at 300 m. In the second case indicated by (b), wind speed increases from 3 kt at 20 m to 24 kt at 220 m and the simultaneous wind direction change is  $100^\circ$ .

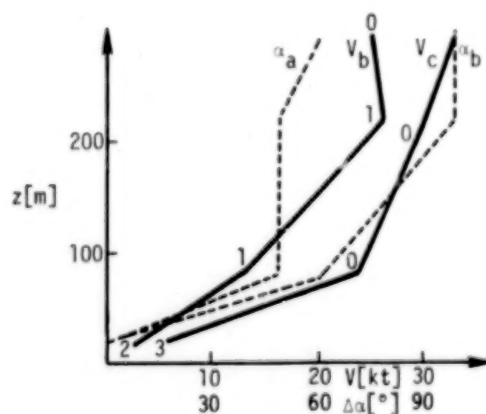


Figure 4. Examples of severe wind shears during periods of marked inversions.

Figure 4 is a plot of recorded wind speed variation with height. These wind profiles are based on two-minute mean values. The numbers on the curve at each measuring station indicate the maximum difference between wind speeds during the two-minute averaging period. It can be seen that the airstream is nearly "laminar", a maximum variation of only 3 kt or less occurs at any given measuring station.

Case (b) illustrates what may happen if the air traffic controller is unaware of the upper wind. He views the existing surface wind conditions as calm. Such a case is illustrated in Figure 5. Figure 5 presents a routine sounding made at Jyväskylä airport in Finland on November 1980. A DC-9-50 departed 0800 local time from runway 12. When turning on to course, a  $180^\circ$  turn at 1500 feet, the aircraft suddenly lost 500 feet in altitude and the pilot had to fight to maintain control of the aircraft. The apparent reason for this incident was departing into a strong tailwind created by a marked inversion.

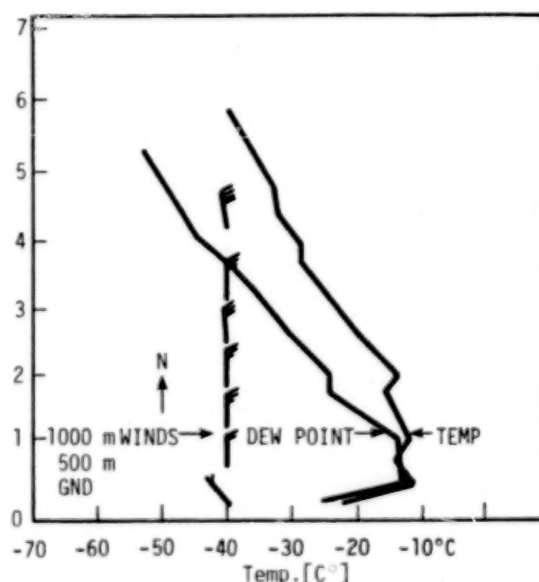


Figure 5. Prevailing weather conditions at Jyväskylä on November 11, 1980, when a DC-9-50 incident occurred.

# Lightning Strike Experience in the NASA F-106B Storm Hazards Program

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Hampton, Virginia

## INTRODUCTION

A heavily instrumented F-106B aircraft is being flown in thunderstorms to gather data for characterizing lightning at aircraft operating altitudes (Figure 1). Conventional weather finding techniques have been supplemented with UHF lightning mapping radar to select the most active storm cells and the most likely altitude for obtaining direct lightning strikes to the airplane. One hundred seventy-six (176) strikes have been obtained in a three-year period, mostly at an altitude of above 25,000 feet.

Although current transport aircraft usually survive relatively unscathed from the effects of direct lightning strikes, manufacturing trends to composite structures and flight critical digital systems in newer aircraft make imperative the need for a reassessment of the lightning hazard at flight altitude. Design and testing of systems that can benefit from the lighter weight structures and more versatile control systems require the existence of a statistical data base defining the lightning hazard. In addition to the electromagnetic characteristics of nearby flashes and direct strikes, there is also a need for a comprehensive treatment of their effects on structures and the electronic systems vital to flight. The NASA Storm Hazards Program is providing useful data in all these areas.

Initial penetration flights of the NASA-owned and operated F-106B aircraft were conducted in 1980 in Oklahoma under the guidance of the National Severe Storms Laboratory's Rough Rider Project team. Later tests were conducted from Langley Research Center with radar support from NASA Wallops Island Facility.



Figure 1. Lightning Research

The technique evolved for operations at Langley in 1982 is depicted in Figure 2. The National Weather Service WSR-57 weather radars at Patuxent River, Maryland; Hatteras, North Carolina; and Volens, Virginia, were continuously monitored during the day to detect the occurrence of third level radar echoes within 150 miles of Langley. Altitude of storm cell tops were determined by the Wallops SPANDAR radar, a high resolution S-Band radar, and the most likely cells were surveyed for electrical activity using conventional indicators, i.e., short-range time-of-arrival direction finders, and long-range

	1980	1981	1982
FLIGHTS	40	48	49
PENETRATIONS	69	111	239
STRIKES	10	10	156

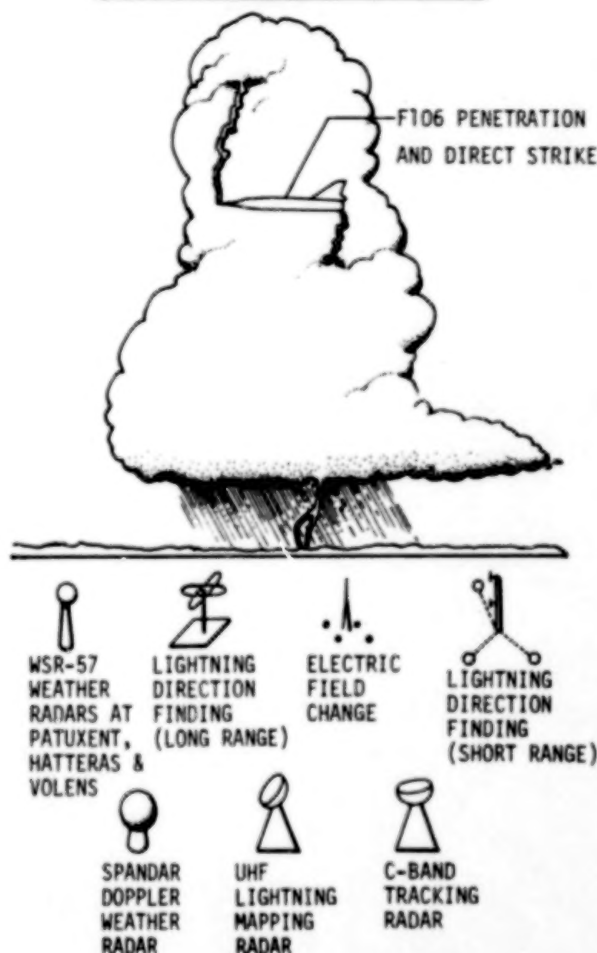


Figure 2. Storm Hazards '82 Operations

magnetic field direction finders. For about one month in 1982, a UHF lightning mapping radar at Wallops was used with good effect to provide three-dimensional data on lightning. A C-Band tracking radar provided aircraft position data to Wallops personnel; the aircraft Inertial Navigation System (INS) position was downlinked to personnel at Langley. Aircraft operational control was exercised either from Wallops or Langley depending on the situation. The aircraft carried its own weather radar, and the pilot always exercised a final option on selecting penetration locations and heading.

In 1980 and 1981, ten lightning strikes to the airplane were received each year. During this time, most penetrations were accomplished at 10,000 - 15,000 feet altitude in accordance with the history of lightning strikes to aircraft as summarized in Figure 3. In 1982, most penetrations were flown between 25,000 and 35,000 feet altitude, with a dramatic increase to 156 in the number of strikes. The distribution of strikes with altitude is shown in Figure 4 for 168 of the strikes. In addition to the altitude change, several other factors that were changed in the 1982 operation contributed to this large increase. These include:

1. More storms available through extension of the aircraft operating range from 100 nautical miles to 150 nautical miles from Langley.

THUNDERCLOUDS MAY RISE  
TO 60,000 FEET

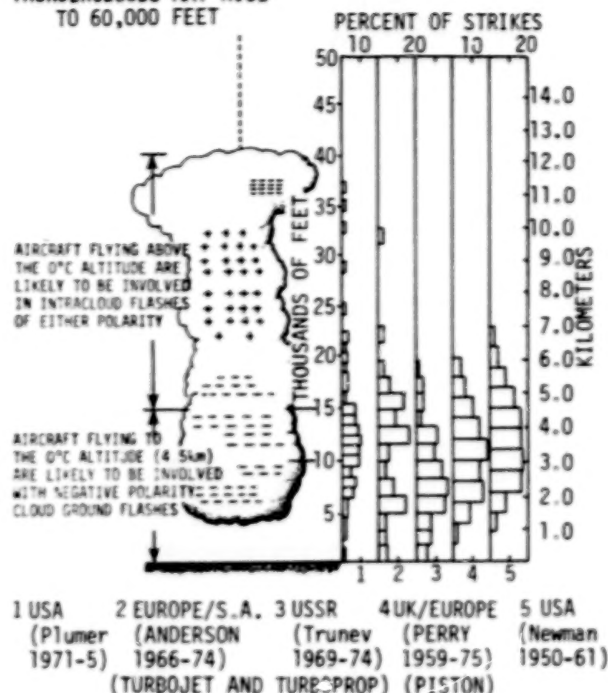


Figure 3. History of Lightning Strike Incidents vs. Altitude

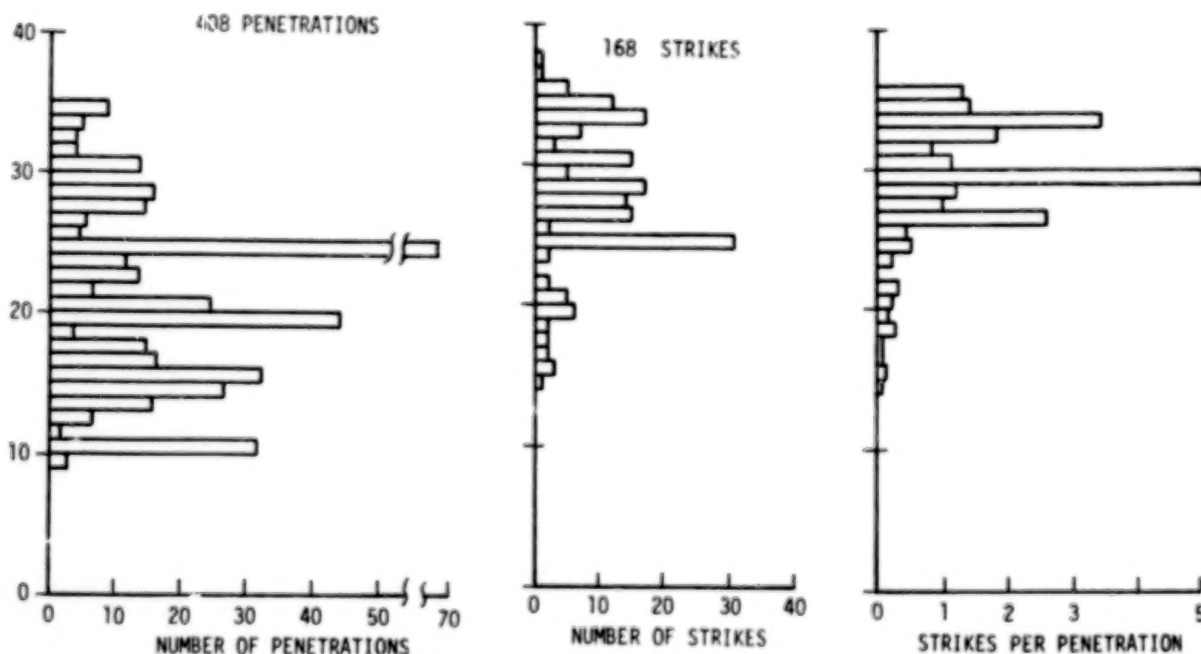


Figure 4. Storm Hazards Program History of Lightning Strike Incidents vs. Altitude, 1980, 1981, & 1982

- Existence of more moderate level thunderstorms during daylight hours within 150 miles of Langley than heretofore.
- More efficient use of flight time through the addition of the second control center at Langley to supplement the Wallops control providing greater geographic coverage and equipment redundancy.
- Improved location of lightning activity through the addition of the UHF lightning mapping radar from late July through August.
- Addition of the long-range lightning direction finding system in early August.
- Less equipment outages (In 1981, the F-106B was grounded for two months due to engine problems).

However, it is felt that the principal change was due to flying higher. This was borne out by the activity shown on the airborne field mills, which was also downlinked to the Langley control center. Typical results are shown in Figure 5 which indicate few separated charges down low (17,000 feet), but the existence of many more charge centers at higher altitudes. The sequence shown in Figure 5 is believed to be typical. At 25,000 feet, significant changes in field charge were indicated, and a positive nearby flash and a negative direct strike were recorded. Later, and down low at 17,000 feet, very little field mill activity was observed. Still later, back up high (24,000 feet), many changes in charge level were observed including another negative charge strike. Although there are significant changes in aircraft position within the storm during the data interval shown, these data represent the general experience, and the physical ramifications of this behavior

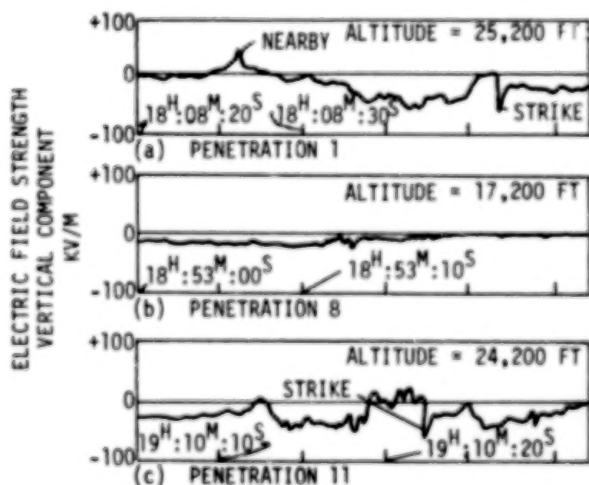


Figure 5. Electric Field Strength Measured During Three Storm Penetrations From Flight 82-027, July 11, 1982

are represented in the distribution of strikes with altitude (Figure 4).

A typical measured electromagnetic sensor response to a direct lightning strike is compared with a numerical model simulation in Figure 6, using a finite element representation of Maxwell's partial differential equations of the basic airframe. In general, the agreement is good, although higher order terms in the prediction need further analysis.

To date, about 138 strikes have been obtained above 25,000 feet, mostly intracloud strikes. Peak amplitudes range from less than 1,000 amps to about 15,000 amps. Next year, some effort will be made to obtain data from cloud to ground strikes, using the advanced lightning finding techniques already described, and operating at altitudes of 10,000 feet or below.

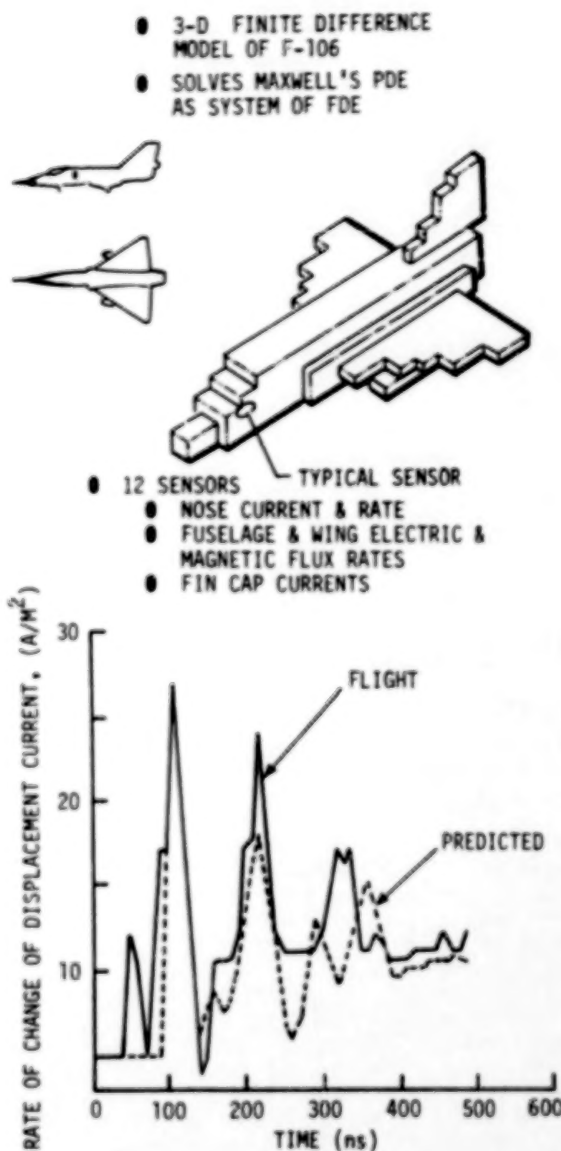


Figure 6. Comparison of Theoretical Prediction with Flight Measurements



# Wind Shear and Vortex Wake Research in UK. 1982

Alan A. Woodfield  
Royal Aircraft Establishment  
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## 1.0 INTRODUCTION

The Royal Aircraft Establishment, Bedford (RAE) has been actively involved in research on both Wind Shear and Vortex Wakes, for many years (REF 1,2,3 & 4). The years 1982 and 1983 will see the successful completion of many of the recent programmes which have already led to major steps forward in our understanding of both wind shear and vortex wake and their impact on aircraft. This increased understanding is reflected in the development of systems and advice to help pilots, and in providing rational scientific methods to assist in advising Certification Authorities and all those interested in improving flight safety.

Wind Shear and Vortex Wakes are related in that they both are invisible enemies of aircraft in the form of large disturbances in the atmosphere and both cause major accidents. They are considered separately in this report, as is the similar problem of building wakes at airports.

During the late 1970's a considerable volume of research on wind shear was initiated by the American FAA following the Boston, New York and Denver accidents to civil airliners. Similar work was also started in the UK. This research resulted in useful advice to pilots about wind shear; better attempts by the meteorologists at forecasting wind shear conditions; and some useful ideas for wind shear measurement and warning systems. By 1980, there were still three major research tasks outstanding:

- Worldwide measurements to give reliable estimates of probability and details of the forms of large wind shears.
- Developments of real-time wind shear measuring systems for ground or airborne use.
- Establishing relationships between measured wind shear and the potential hazard to an aircraft, or class of aircraft.

Without results from these three areas, it is difficult for Certification Authorities to suggest workable requirements, or for avionics companies to provide adequate display information for pilots. The RAE have established programmes in all three areas in collaboration with UK industry and the United Kingdom CAA. The work and some highlights from the results are presented in this note. It is worth noting that progress towards installing suitable equipment in aircraft and at airports will be very slow if Certification Authorities do not make any requirements. Until this year, these authorities could claim with considerable justification that:

- Suitable proven equipments for wind shear measurement did not exist;
- Improved training seemed to reduce accidents from wind shear.

These arguments, together with the political and economic climate, effectively stalled any possibility of producing requirements. Although the political and economic climate has not changed, the situation on both (a) and (b) is now very different. Several systems for measuring and displaying wind shear information have now been tested in flight, particularly in the UK. Also, the tragic New Orleans accident and the Air India B-747 accident at Bombay, have dramatically highlighted the continuing menace of wind shear.

Turning to Vortex Wakes: the RAE withdrew from all Civil Vortex Wake experiments in 1977, although some reports continued to be published as interesting events arose, such as incidents in cruising flight (REF 4), or as further analysis of existing data was completed (REF 5 & 6). However, in 1981, an RAF F4 (Phantom) aircraft crashed in a formation landing and early in 1982, an RAF Hawk Trainer also crashed. The RAE advised, and the Boards of Enquiry agreed, that Vortex Wake encounters were very likely causes of both accidents. Several flight measurements of vortices were made to verify this, using the unique fast response flow measurement probe on the RAE HS-125 research aircraft. From these measurement and past experiments in the USA and UK, the RAE have developed a relatively simple and rational method of assessing potential vortex hazard, and identifying the relative susceptibilities of various military and civil aircraft. The main lessons from this work are described in this note and should provide both civil and military authorities with a means of assessing separation requirements for existing and proposed new aircraft, such as the proposed B-747 development and, at the other extreme, the new Ultra Light aircraft.

The third topic addressed is Building Wake Turbulence. At some airports, such as London (Heathrow), constraints on space have led to the construction of large aircraft maintenance buildings near the runways. At Heathrow, the buildings of the British Airways Engineering Base are South of the last kilometre of the approach to Runway 28R. Pilots are warned to expect large wind changes on this approach in SW winds of 15 kt or more. Plans to construct more large buildings are in hand for Heathrow and other airports, but we have as yet no means of assessing their potential hazard in any objective way. A joint programme between the RAE and Bristol University is addressing this problem and is described in this note.



## 2.0 WIND SHEAR PROGRAMME

This section describes the work on:

- Wind shear measurements
- Hazard level determination
- Wind shear detection and display systems.

### 2.1 Wind Shear Measurements

#### 2.1.1 Airline Flight Data Recordings

All major airlines in the UK, and airlines in several other countries, but not including the USA, use continuous flight data recording to monitor system health (especially engines) and provide information on operating events to improve operating techniques and flight safety. These records contain a wide range of flight situation parameters and in 1978, the RAE approached British Airways (BA), with the support of the CAA, with a proposal to use such records to obtain wind shear measurements. The programme was agreed and, following an initial trial period in Summer 1980 (1205 landings, REF 7 & 8), a programme of analyzing the final 2 mins of every landing of BA B-747 aircraft for about 12,000 landings started early in 1981. At September 1982, data from 9000 landings had been analyzed.

The programme has three aims:

- To provide statistics on the probabilities of encountering severe wind shear at individual airports in a worldwide route structure;
- To provide examples of large wind shear to improve our understanding of the forms of shear and the associated aircraft behavior;
- To prove the usefulness of the Discrete Gust Analysis methods (REF 9) in detecting wind shear and provide a method for routing application at British Airways.

Initially, the flight data are processed at BA to extract head wind, cross wind, aircraft heading, and height data at one-second intervals for the 2 mins before touchdown. British Airways process these data through a simple wind shear identification programme and identify:

- Landings where the shear magnitude exceeds a predetermined threshold, which are called alerts;
- Landings where a combination of wind and aircraft heading change will give a significant apparent wind shear when considering only head wind changes. These are not checked for alerts but head wind, cross wind, aircraft heading and height are passed to the RAE;
- Landings where more than 20% of the data has lost synchronization is rejected at BA.

British Airways pass to RAE the head wind and height data for all landings, other than those identified with (b) and (c) above. At the RAE, the data are subjected to a series of checks to reject all runs with suspect data, after visual inspection, and to check the validity of all the runs with events at the 5% probability level or less. The alert threshold is set at about the 1.5% probability level.

The wind shears (and turbulence) are identified using the Discrete Gust Analysis Method (REF 9) developed at the RAE by J. G. Jones. This is used to identify particular patterns in the head wind data: In this case, single and double ramps (Figure 1). These are filtered to identify the length of the ramp as well as its size.

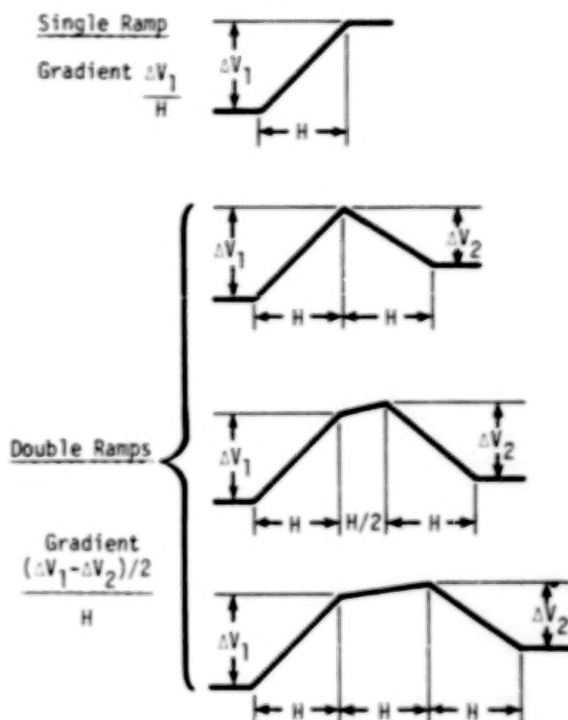


Figure 1. Wind Shear Patterns

Typical data after 9135 landings at a total of over 70 airports around the world is shown in Figure 2. The cumulative probability plots show a remarkably consistent relationship with an exponential distribution form (straight line on the log-linear plots). The data include both turbulence and isolated wind shears. This consistency means that extrapolation to predict the severity of wind shears at the  $10^{-7}$  probability level for landing can be readily justified. For a single ramp 600 m long, which has been suggested as a critical length in ICAO discussions, the 1 in  $10^7$  landings case is likely to be a shear of about 27 knots. Also the data show that the longer shears of about 600 and 1200 m can be normalized when plotted as  $(\text{Speed Change}/(\text{Ramp Length})^{1/3})$  so that shear at other lengths can be predicted readily, e.g., at 1500 m shear length the 1 in  $10^7$  landings case is likely to be a shear of 37 knots.

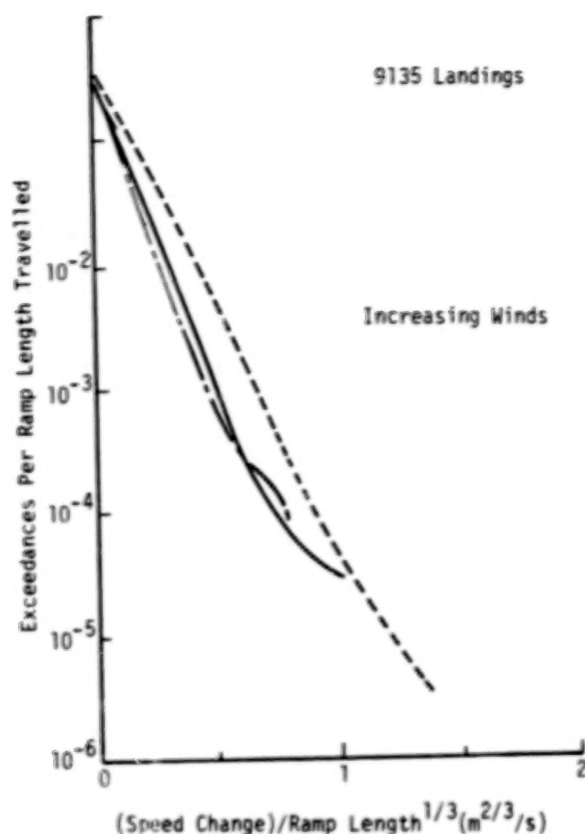
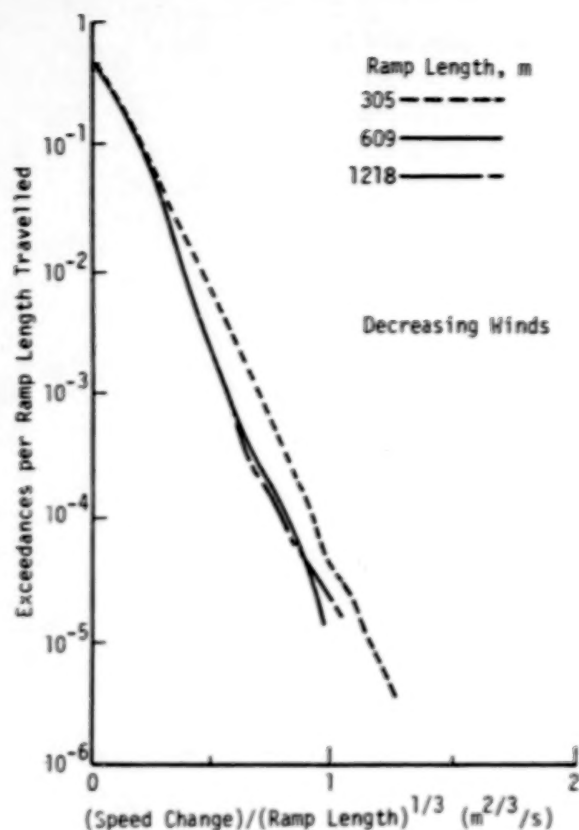


Figure 2. Cumulative Distribution of Single Ramps (British Airways Records)

Data for individual airports and both single and double ramps of 600 m are shown in Figure 3, and cover a wide range of conditions in terms of

airport latitude, topography, time of day, etc. There are significant differences in the level

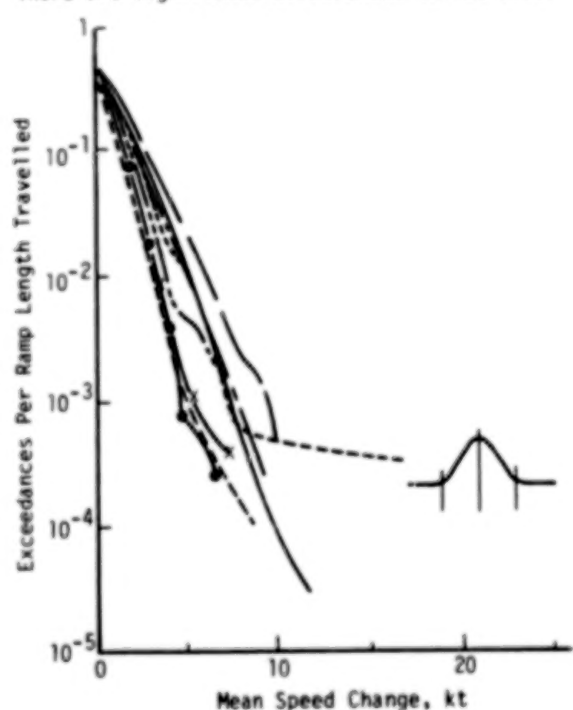
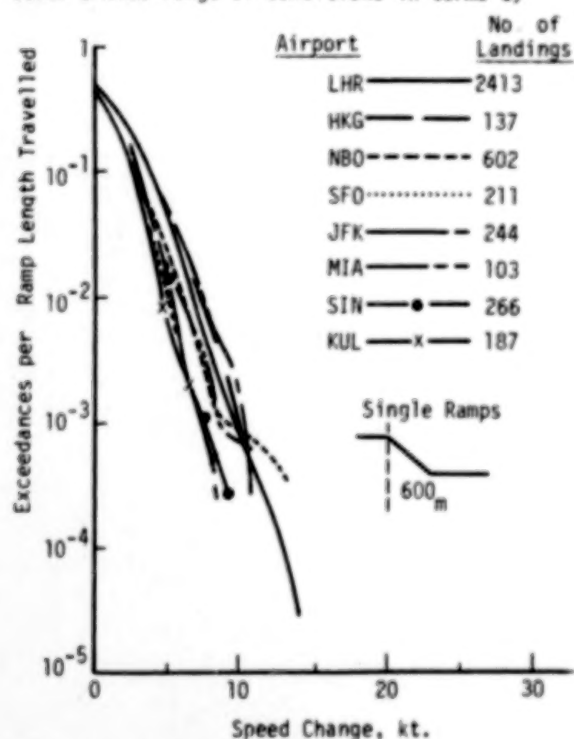


Figure 3. Cumulative Distributions of Single and Double 600 m Ramps at a Selection of Airports

of activity at different airports, but, despite the much smaller sample sizes, the general form of the distributions are well established. Airports with significant thunderstorm activity are covered very adequately as the data includes late afternoon and early evening landings at Kuala Lumpur and Singapore, which have very high probabilities of thunderstorms. The rate is almost one a day in the most active months (Oct./Nov.). The data also cover Miami in the USA, which has quite a high probability of thunderstorms, although only about half that at Singapore. These three airports are included in Figure 3, but are all relatively inactive.

One other aspect being studied from the statistics is the distribution of wind shear with height above ground. The data are grouped into approximate height bands between 0, 250, 500, 1000 and 1500 feet for different airports. The

results have yet to be fully assessed; but, as the hazard from wind shear is greater as the available decision height decreases, the data will improve the estimation of the worst cases.

The statistical data is already proving valuable in helping the RAE to advise the Hong Kong authorities on possible wind shear hazards at proposed sites for a new airport.

Examples of head wind variations with various types of wind shear encountered are shown in Figure 4 (data from REF 7). The two largest events recorded up to August 1982 are shown in detail in Figure 5 (Melbourne) and Figure 6 (Anchorage). In Figure 4, there are examples of a low-level jet at San Francisco (16.6 kt in 4s), a storm front at Calcutta (13.6 kt in 4s), an on-shore wind at San Francisco (12.8 kt in 16s), and a mountain wake at Hong Kong (Double ramp of average 10.7 kt and 4s each ramp).

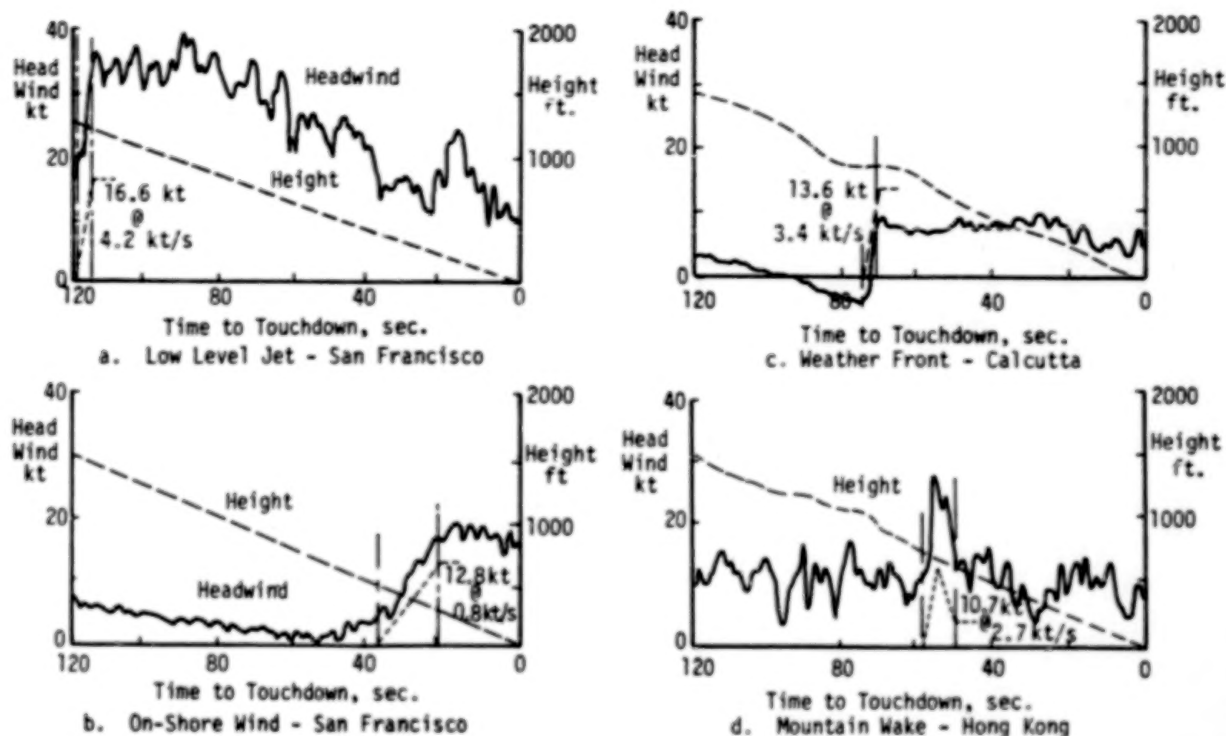


Figure 4. Wind Shear Measured from British Airways Flight Data

The event at Melbourne, Figure 5, demonstrates the effectiveness of the calculation of vertical as well as horizontal winds and shows an event starting with a 1000 ft/min downdraught and about 35 kt loss of head wind. The pilot applied thrust to a level that would normally give level flight but this was only sufficient to stabilize descent rate at slightly more than

normal for an approach. The aircraft finally recovered when the wind shear ended and the aircraft was about 150 ft above the ground. The other major event at Anchorage, Alaska, was of a similar magnitude and the pilot overshoot. (Note that the Ground Proximity Warning System (GPWS) operated 1 or 2 seconds after the pilot decided to overshoot.)

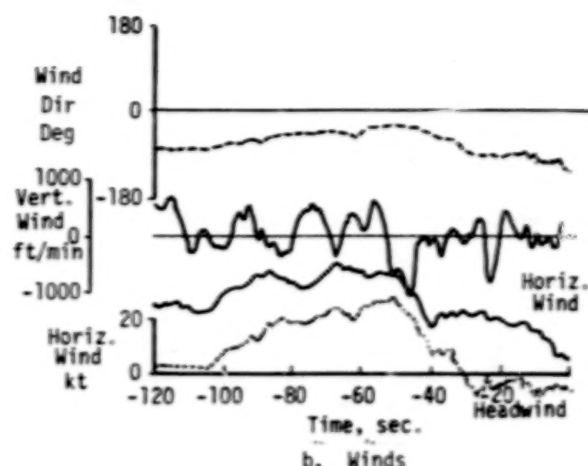
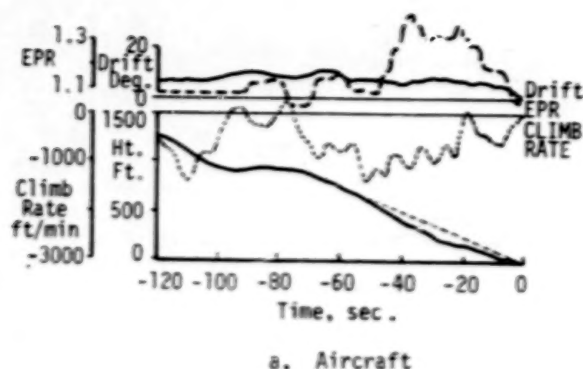


Figure 5. Wind Shear at Melbourne

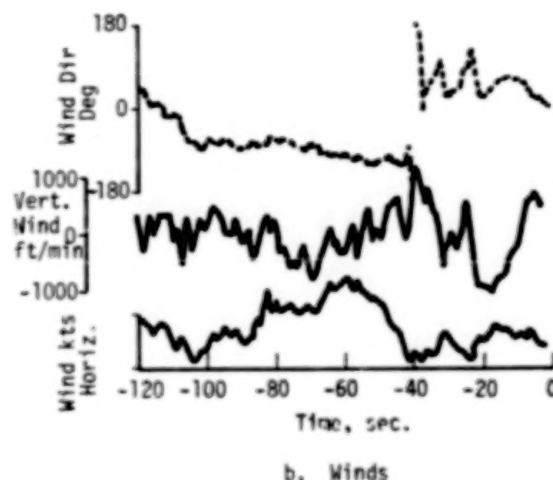
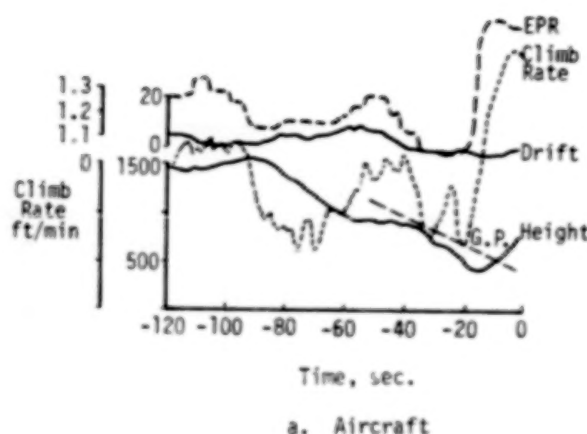


Figure 6. Wind Shear at Anchorage

The routine collection of BA data will end in March 1983, as any significant extension of the statistical data base would be both uneconomic and, in view of the orderly nature of the results to date, unnecessary. The NLR, Holland, have been involved in a similar data collection programme from KLM Aircraft (REF 10 & 11), but without the assistance of discrete gust methods were unable to test and summarize their data readily. Following publication of REF 7 & 8, they are now programming the RAE method so that the data from KLM and BA can be compared directly. There are about 8000 landings and take-offs during 1978 in the KLM data and a further period of data collection is expected in 1983. This data will be exchanged with the RAE data.

Collection of large events from BA is expected to continue beyond March 1983 under the CAA's special event programme CAADRP. The RAE will provide programme advice and a consultancy service.

## 2.1.2 Thunderstorm Wind Shear

Quite a few of the major aircraft accidents from wind shear have occurred in winds associated with thunderstorms. In the Summer of 1982, the US National Center for Atmospheric Research (NCAR) and the University of Chicago organized an extremely successful programme around Denver, Colorado - the Joint Airport Weather Studies (JAWS) Project (REF 12) - to investigate the structure of thunderstorms and their winds. The RAE were fortunate to be invited to participate with the HS-125 research aircraft (Figure 7).

The RAE HS-125 was in Colorado for three weeks in June/July 1982, and flew 34 experimental sorties of which 16 were flights in thunderstorm winds at heights between 1000 and 3000 ft above ground level. The other flights covered a variety of related tasks. The RAE programme was supported by funds from the UK Department of Industry, UK Ministry of Defense, CAA, Sml's

Industries plc., US NCAR, Marconi Avionics plc., Ferranti plc., and Signal Processors Ltd.



Figure 7. RAE HS-125 Research Aircraft

In addition to its basic instrumentation to measure turbulence, including wind shear, in three axes at frequencies up to about 20 Hz (a minimum wavelength of 6 m at typical speeds used for JAWS flights), the RAE HS-125 was unique among the participating aircraft in having a wind shear detection and display system fitted... the Smiths Industries 2 pointer VS/ERO (Vertical Speed/Energy Rate Indicator). It also carried the detection elements for two other systems, viz:

- a. Laser True Airspeed System (LATAS), which detects wind shear several hundred metres ahead of the aircraft;
- b. Marconi AD660 Doppler Velocity Sensor, which could be used as the basis of a ground speed/airspeed display.

These systems are discussed in a later section.

The editing and analysis of the JAWS flights is proceeding and an example of one of the more dangerous microburst events is shown in Figure 8. The primary microburst pattern has smaller events on either side. The main event sees the head wind increase by about 25 kt following the initial dip of 8 kt. It stays at a mean of about 25 kt for 5.5 seconds and then falls by 35 kt followed by an increase of 18 kt. The final action is a smaller drop of 10 kt. The main event covered a distance of about 2.2 km, or about 30 - 35 seconds of flight time at normal jet transport aircraft approach speeds. Calculation of the downdraught is not yet complete but the mean flight incidence remains constant whereas the pitch attitude increases by about 3 degrees. This indicates a downdraught of about 1200 ft/min. The flow was also very turbulent and produced normal acceleration changes of  $\pm 1g$  at the speed of

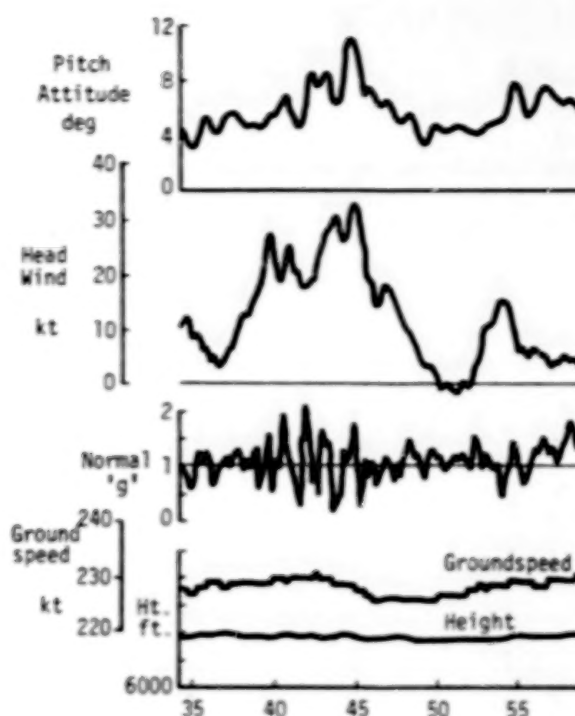


Figure 8. Thunderstorm Microburst  
- JAWS Project  
RAE HS125 - Flight 792,  
Run 3.

250 kt CAS used for the flight tests. Full analysis of events such as these will provide a detailed understanding of the form of one of the more dangerous forms of wind shear by identifying not only its magnitude, but also its development and decay. From this should come a better understanding of the meteorological conditions likely to cause microbursts.

In marked contrast to the turbulence in a microburst, flight in the vicinity of intense precipitation, including 3 cm diameter hail, was generally in calm air. Wind data for these flights are being analyzed as are the results for thunderstorm fronts and general outflows with wind changes of 30 - 40 kt, which often included significant updraughts on which the HS-125 could almost soar at idle thrust.

The data from the JAWS project will give a better description of some of the worst shears that nature can produce, which will be of great value for use in wind shear simulations to develop detection and display systems. Also, by studying wind shear events at airports on the BA 8-747 routes, it may be possible to estimate the probabilities of encountering a significant microburst.



## 2.2 Hazard Levels

At first glance, it may seem strange that there is still no straightforward way of estimating the potential hazard to an aircraft of a given variation of horizontal and vertical wind (wind shear). There is general agreement that the height excursion from the intended flight path is a measure of the potential hazard and, as this is a greater hazard near the ground, it is best considered as a fraction of the height available.

The difficulty in relating such height losses to a given wind shear lies in the length of wind shears, e.g., the 30 or so seconds taken to pass through the microburst of Figure 8 at approach speeds. During a time interval of this length control actions will be taken in both pitch and thrust by either a pilot or an automatic control system. The control response will have a significant, even dramatic, effect on the height excursions. This is clearly illustrated when the stick (and throttle) fixed response of REF 13 is compared with piloted simulation (REF 14) through the same wind shear. In the first case, the usually lightly damped long period (Phugoid) response is excited, whereas in the piloted case, it is almost totally suppressed. Also in the first case, very large height oscillations occur which are largely absent from the piloted case. Pilots respond well to motion with periods longer than a second or two, and the Phugoid is typically of 30-40 seconds period; so the above result should not be very surprising.

Piloted simulator studies have been used for many tests. However, such simulation introduces a much wider number of variables than simplified analytical methods, so it is highly desirable to establish a suitable analytical method for assessing susceptibility to wind shear. This method should then be tested using piloted simulation.

For any analytical method, the form of pitch and throttle control has to be defined from the start. One simple pitch control mode considered by the author is flight with constant pitch attitude. This is not unreasonable as it is pilots' control of pitch attitude which modifies the Phugoid and introduces the concept of speed (or flight path) stability. The basic longitudinal motion is modified to a pair of exponential modes. One is mainly a well-damped incidence response and the other is mainly a lightly-damped speed response. Figure 9 shows some typical responses with pitch constraint and without any throttle action. The single ramp head wind change results in an almost constant height rate. The double ramp downburst (single ramp downdraughts are very unlikely as the mean vertical wind is zero) produces a loss of height.

Actual maximum height deviation will depend on the thrust response function, or a reversal of

the wind shear (or both). It is this dependence of height deviation on pitch and thrust control functions and wind shear pattern, which makes it difficult to find generally accepted ways of relating the potential hazard to the wind shear.

However, the use of pitch constraint seems a promising starting point, as do the wind shear patterns identified by discrete gust methods. Current research at the RAE is investigating various throttle control modes suggested by study of throttle activity on BA B-747's and other aircraft.

It is hoped that this work will identify the most important aircraft characteristics (e.g., speed, stability, thrust margin, minimum drag speed), and wind shear characteristics (e.g., speed change, length). Aircraft can then be categorized in groups with similar susceptibility to shear. This will also give a basis for presenting the most useful information to pilots.

This study should be completed during 1983, including tests of various features in a piloted simulation. It is the most important aspect of wind shear yet to be resolved as, without it, it is very difficult to establish how to use wind shear data to help pilots, other than through generalized warnings.

## 2.3 Wind Shear Detection and Display Systems

These systems can be divided into two groups:

- a. Ground based sensors
- b. Airborne sensors

To be a viable commercial proposition and, perhaps even to be considered as acceptable for complying with any Aviation Authority requirements, any system must provide continuous information of value to pilots and, for ground based systems, air traffic controllers. This information cannot be wind shear, as the significant events are rare; and, because rapid response is essential when wind shears occur, it is vital that pilots and air traffic controllers have confidence in the system. This can only be earned by long experience of receiving correct (and useful) information without "soft" failures prior to its first genuine significant wind shear indication. Thus, it is vital when designing systems to consider first their value in normal operating conditions. Having done this, then the price must be made acceptable.

In addition, the author has always considered that any airborne display system must be prominently located on (or perhaps close to) the primary flying display and provide continuous analogue information during all flights. The idea of a wind shear warning system without an associated analogue display is impractical. Real events are very rare. This means that protection

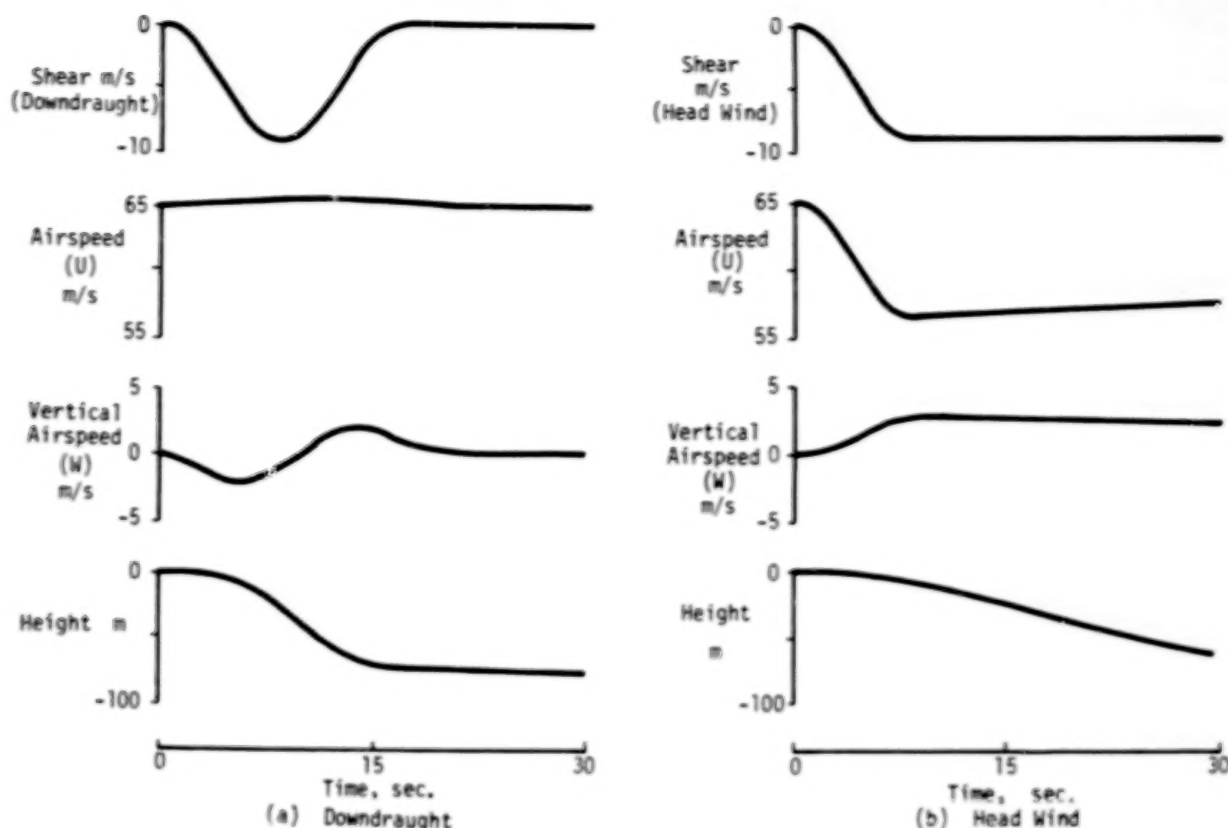


Figure 9. Response to Wind Shear with Pitch Constraint

against nuisance events is very difficult without introducing a lot of smoothing with associated lags in producing the warning. Delays have a dramatic effect on height loss, which is approximately proportional to delay squared.

Thus, 'warning only' systems are likely to be either too late or generate a lack of confidence because of nuisance warnings so that pilots need to crosscheck with other instruments before responding. This creates further delay.

In the following discussion on detection and display systems, brief mention will be made of known systems, but only the UK activities will be discussed in any detail.

### 2.3.1 Potential Flight Path/Energy Rate Displays

These are the only type of airborne display that are commercially available and they are advertised by the following three companies: Safe Flight, Inc., USA, SFENA, France, and Smiths Industries plc, UK. The author only has experience with the Smith Industries system, which is the two-needle VS/ERI (REF 15). Potential Flight Path Displays offer similar capabilities and are most easily provided on Electronic Displays (Head Up or Head Down).

The basic principle of these systems is to establish the rate of change of energy,  $E$ , where

$$dE/dt = V_{True}(dV_{True}/dt) + g dH/dt$$

To compensate for lags in the air data system when the aircraft is responding to thrust, or flight path changes, a pair of accelerometers (normal and longitudinal) are fitted, and resolution of these into flight path axes required measurements for estimates of incidence angle. The rate of change of energy can be displayed as the flight path that will be attained if no throttle action is taken to counter the situation.

Various possibilities exist for displaying the information but they are essentially either a situation display of the potential flight path (or potential climb rate), or a throttle director. Of the various systems, only the Safe Flight System is a throttle director, the others are situation displays. The situation displays have the advantage of improving thrust management as they can be used to indicate excess thrust as well as wind shear. Potential flight path is probably more useful as it is associated with the Attitude Display, ADI, which together with the Airspeed Indicator (ASI), are the most actively scanned instruments during take-off and

landing. However, the Vertical Speed (VSI) is part of the primary flying instruments and a good location if the ADI cannot be modified. This is where the Smiths Industries and SFENA displays are located.

The Smith Industries VS/ERI is shown in a nominal thunderstorm microburst (downdraught) situation in Figure 10. It has been tested on piloted simulators (REF 15) and flown in a BA Tristar, a Britannia Airways B-737, the RAE BAE 1-11, which has advanced electronic displays, and on the RAE HS-125. In all simulated wind shear cases, the pilots found that the VS/ERI gave their first indication of wind shear and this is supported by a few encounters with moderate shears in the flight trials. However, there is some criticism of using the VSI for the display because many pilots do not usually include it in their primary scan.

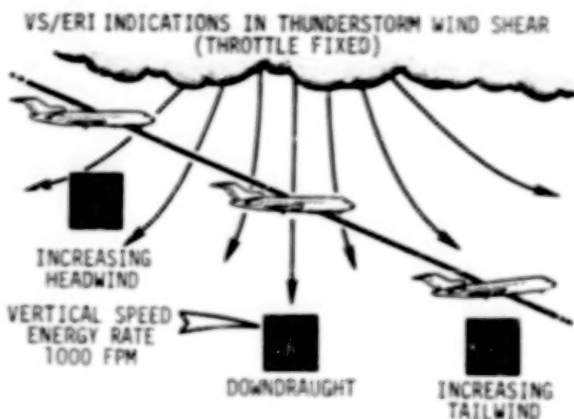


Figure 10. Expected Response of the Smiths Industries' 2 Pointer VS/ERI in a Thunderstorm Microburst

A time history of the response of the Smiths Instrument in the microburst of Figure 8 is shown in Figure 11. This shows the Energy Rate needle responding directly to the rate of change of airspeed. The VSI needle does not respond to the downdraught in this case because the pilot increased pitch angle to compensate. All these types of instruments have a lag in response to wind shear as they must calculate the rate of change of speed. In the Smiths VS/ERI, this lag to shear is about 1.6 sec. Note that: (1) The lag is only about 0.6 sec because the accelerometer terms provide compensation for rates of change of velocity relative to the earth, but not for shears, which affect airspeed with little effect on ground speed; (2) The lag is made greater in Figure 11 by the increase in pitot-static system lag with altitude, as Denver is over 5000 feet above sea level and hot. No scale is shown on the difference between the two needles as the tests in Figure 11 were flown at

It is interesting to note that the difference between the two needles in the microburst is must greater when the speed loss occurs. If

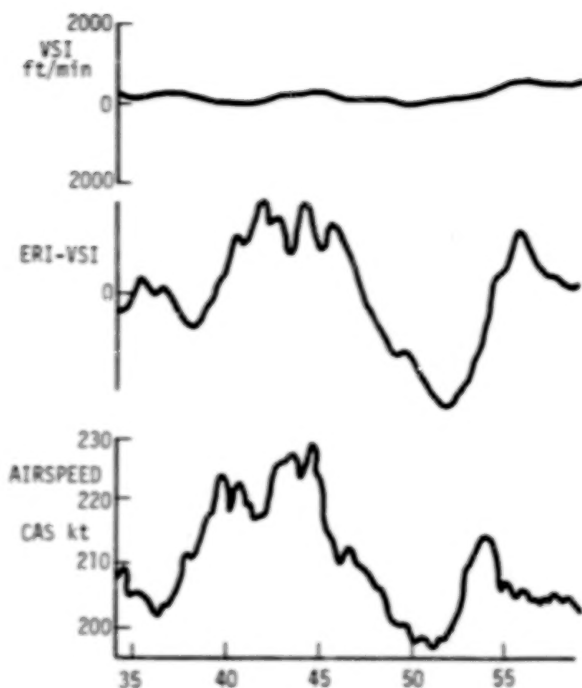


Figure 11. 'JAWS' Microburst Response of Smiths Industries' 2 Pointer VS/ERI

throttle had been used in response to the split between the needles, then a decrease in thrust would not be demanded until the speed was about 15 kt above datum (Datum = 025 kt) but an increase is called for while still 3 kt ABOVE datum. This fortunate response is largely due to the steeper gradient of velocity ( $dV/dt$ ) near the centre of the microburst, where  $V$  is also greatest. Thus giving a much faster response in the midst of the microburst.

### 2.3.2 Groundspeed/Airspeed Displays

The principle of this system is that the hazard from wind shear is reduced by maintaining the highest airspeed compatible with a safe touchdown groundspeed. This principle is generally confirmed by the RAE studies of hazard levels. Thus, instead of flying approaches on airspeed relative to a target threshold speed, they can be flown to keep the lower of either airspeed or equivalent groundspeed above the target speed. In the more usual case with a head wind at touchdown, this will lead to higher than usual airspeeds on the approach.

In the case of a microburst (Figure 8), the use of this groundspeed/airspeed method would inhibit the normal reaction to reduce thrust as airspeed increases because the groundspeed hardly changes and will be the lower speed. Thus, a higher airspeed is maintained to help cope with the downdraught.

The main complications with this system arise when high head winds push the approach airspeed up to flap limiting speeds. If flap angle is reduced, then the speed safety margin falls. In most cases, it would seem best from a performance point of view to keep airspeed below the flap, limiting speed even if it means that the groundspeed falls below the target speed. However, this could be a poor philosophy to adopt if the instrument is to have a clearly defined role as an indicator of minimum speeds.

The head wind variation in the microburst (Figure 8) is a direct indication of the difference that would be seen between the two needles of a 2-pointer ASI. Positive head wind would place the groundspeed lower than the airspeed pointer.

The information on any ASI can be improved by using a laser system, such as the LATAS which looks ahead of the aircraft, as the airspeed source.

The airspeed/groundspeed display does not give any information on downdraughts, which will appear as a transient decrease in normal acceleration and a subsequent increase in descent rate, but it has the advantage of being located on the airspeed indicator which is continuously monitored during both take-off and landing.

### 2.3.3 Laser Airspeed Systems

Laser systems measure airspeed by Doppler analysis of reflections from minute particles (aerosols) in the atmosphere. These particles have an extremely rapid response to airspeed changes and can thus be used as a direct measure of airspeed in a region remote from the laser equipment. Two main types of laser are available:

- Pulsed systems which use time gating to establish the range and short pulse duration (typically 1-2 microseconds) to obtain range resolution. These systems can operate to quite long range and the size of the optical aperture relates to the amount of backscattered signal received. Range resolution is constant at about 300 m.
- Continuous Wave (CW) focused systems where the beam is focused to a waist at remote point to give a maximum level of illumination and thus the greatest signal returns from that point. The sharpness of this focusing is greatest at short range and with a larger optical aperture. Range resolution can be very fine, but increases rapidly at long ranges, and optical aperture is determined by the resolution and maximum range required.

The choice between the two systems depends on whether 300 m range resolution is adequate, and the maximum range required. Research in the UK has concentrated mainly on the CW focused systems. The general principles of the system are

shown in Figure 12. The weak return signal is rapidly converted to a Doppler Spectrum and successive spectra integrated to give very clearly defined spectra. For low altitude wind shear detection, a few hundred integrations are usually adequate and an output data rate of more than 100 samples a second can be obtained.

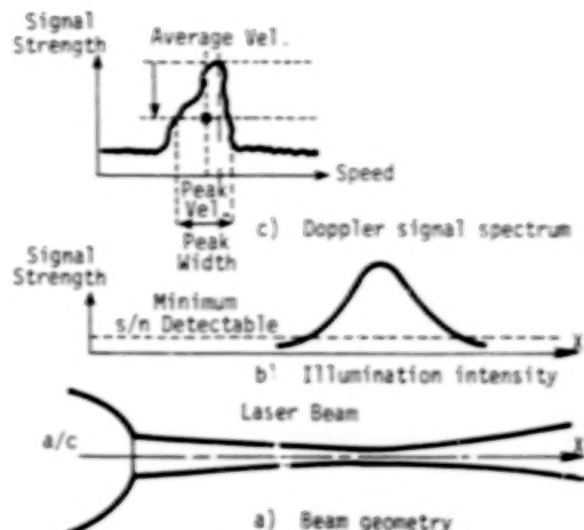


Figure 12. Principles of a CW Focused Laser Anemometer

One useful feature of CW laser signals is information on the spread of airspeeds over a larger range which is given by the minimum and maximum velocities. With this data, it is possible to distinguish real shear from turbulence. Figure 13 shows the RAE/RSRE LATAS airborne laser system signals recorded in the microburst of Figure 8, and the width of the peak of the velocity spectra clearly identifies the real shears. The difference between the laser and the aircraft true airspeed is a direct measure of the shear gradient over 250 m (about 4 seconds of flight time at normal approach speeds). These shear gradients have values of around 4 kt/sec (2 m/s/s) at approach.

The RAE in close collaboration with the Royal Signals and Radar Establishment (RSRE), who have been responsible for the development of the optics and signal processing equipment, have tested both ground based and airborne CW laser systems. Both systems use eye-safe carbon dioxide lasers

The main aims of the research programme have been to establish the character of laser wind signals and the essential features required in production versions for regular use at airports or in aircraft.

#### 2.3.3.1 Ground Based System

A ground based system (Figure 14) was tested at RAE, Bedford, and the results compared well with more conventional anemometer data. Power Spectra



and Discrete Gust Analysis of these data confirmed that the laser system was a reliable source of wind information. The system used 30 cm diameter reflecting telescopes, was monostatic and had an output power of 5 watts. It was used satisfactorily out to ranges of about 1 km.

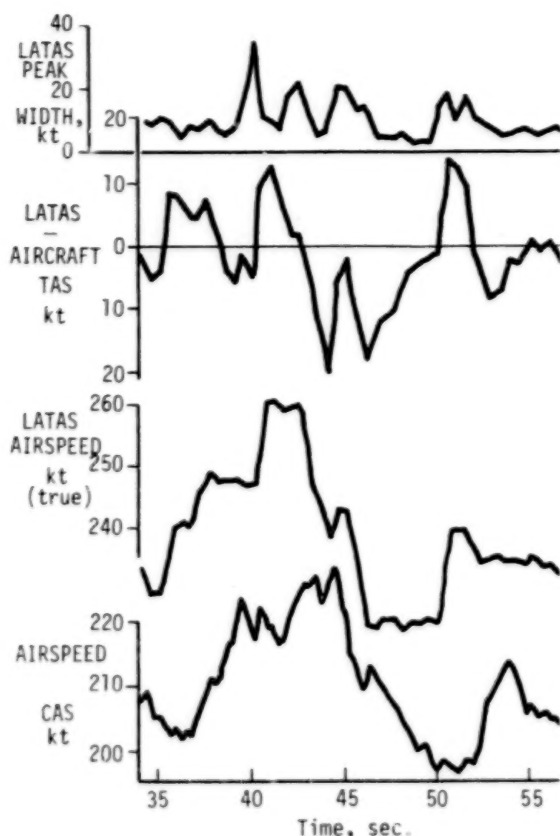


Figure 13. 'JAWS' Microburst Response of RAE/RSRE 'LATAS' System

Any ground based system for airport use would need to make wind measurements from about 0.5 km to 6 - 10 km and preferably with a full 360 deg azimuth scan. The measurements could then be used to give air traffic continuous wind information for all landing and take-off points, and also identify any wind shear development. Measuring both its magnitude and its track relative to landing and take-off paths.

The main problem with operating at such long ranges with a CW system is the large size of the optical aperture required which is about 1-2 m diameter. This could be expensive, although full visible wavelength accuracy is not required, and, in theory, there may be a limit to the effective aperture size, despite the geometric size, because of the effects of small scale turbulence. There is not appropriate experimental data to confirm this limit on effective aperture, but, if the present estimates are correct, it may not be possible to use apertures greater than about 1 m diameter. The author views this theoretical limit with some scepticism as:

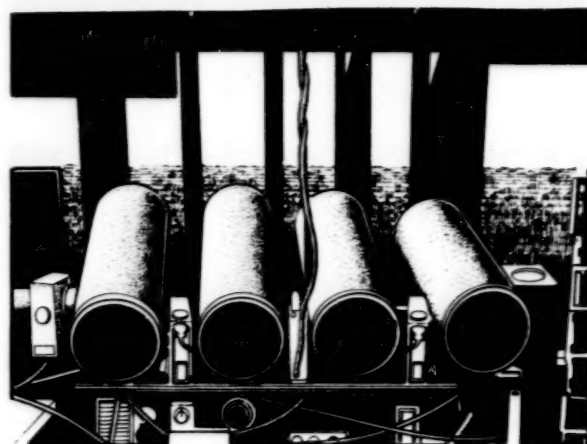


Figure 14. Ground Based Laser Airspeed System

- a. The theoretical data is only supported by experimental results from bi-static systems with the beam only a few feet above an arid surface, and
- b. Other limitations on laser effectiveness have proved less of a constraint than theoretical estimates would suggest.

However, until tests can be made to see whether such a limit on effective aperture exists, it will be difficult to persuade commercial companies to invest in the development of an airport system based on CW lasers. Pulsed lasers do not rely on focusing for range definition and may be more suitable for a ground based system. However, as yet there has not been a detailed evaluation of a pulsed system against other wind measuring systems.

#### 2.3.3.2 Airborne System

An airborne system (LATAS), Figure 15, (REF 16), has been flying in the RAE HS-125 for about two years and is proving very successful and reliable for measuring airspeeds at remote points up to about 300 m ahead of the aircraft. As Figure 13 shows, this gives extra vital seconds of warning of wind shear. The system uses CW optics made by RSRE and a 3-watt waveguide carbon dioxide laser manufactured by Ferranti. Based on earlier experience, the critical areas for reliability were expected to be the laser, the optical train and the germanium window used to transmit the infrared beam. In the event the lasers have been operating for periods of up to six months without any attention, the optics have not required any adjustment at all, except after laser changes, and the front surface of the germanium window, with its special protective coating is unmarked after 2 years of flight trials, which included flight in soft hail. Figure 16 shows the state of the surrounding paint, which was pitted down to the metal, after flying in heavy rain and soft hail. The window surface is unharmed. Reliability of this level from prototype experimental equipment argues very well for a reliable commercial development.





Figure 15. Airborne Airspeed Laser System (LATAS)

The only real obstacle to commercial development is finding a suitable incentive for airlines to purchase such a system. This requires either that the unit earns its keep by saving aircraft operating costs, or that airworthiness requirements call for such a system to be fitted. The

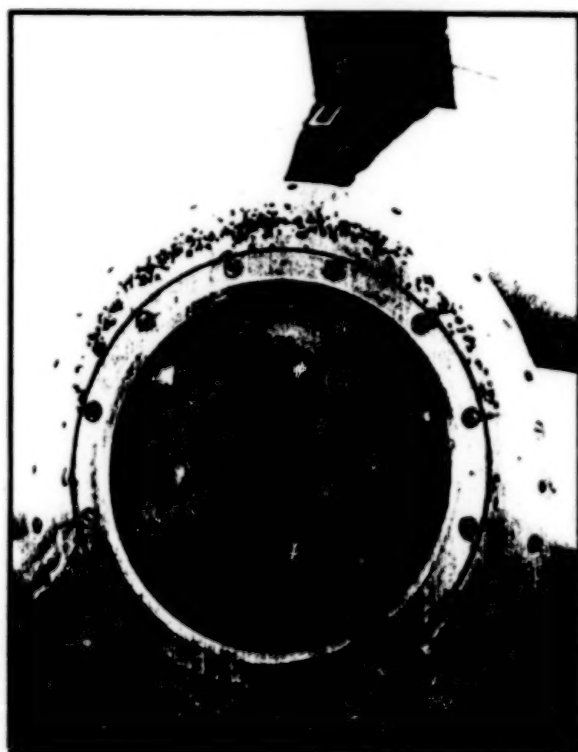


Figure 16. Effect of Hail on Germanium Window

research programme in the UK is addressing possible features that could produce savings in operating costs. Such as:

- an efficient autothrottle sensor which is responsive to significant shear with negligible lag and yet able to ignore short period turbulence;
- a control system for tyre spin-up that accurately measures both ground and tyre speed;
- a sensor for active ride smoothing and/or gust load alleviation control systems which provides adequate lead.

For this last application the system has function at all heights, and great advances have been made in obtaining reliable signals in very low backscattering conditions at high altitude. Figure 17 shows an example of the signal to noise ratio measured in a climb to 43000 ft pressure altitude. To give some relationship between this data and visibility, it should be noted that the quite high signal to noise ratio at low altitude corresponded to a visibility of about 70 nm. The system is not yet able to obtain a usable signal in all conditions at high altitudes, although there are no problems near the ground.

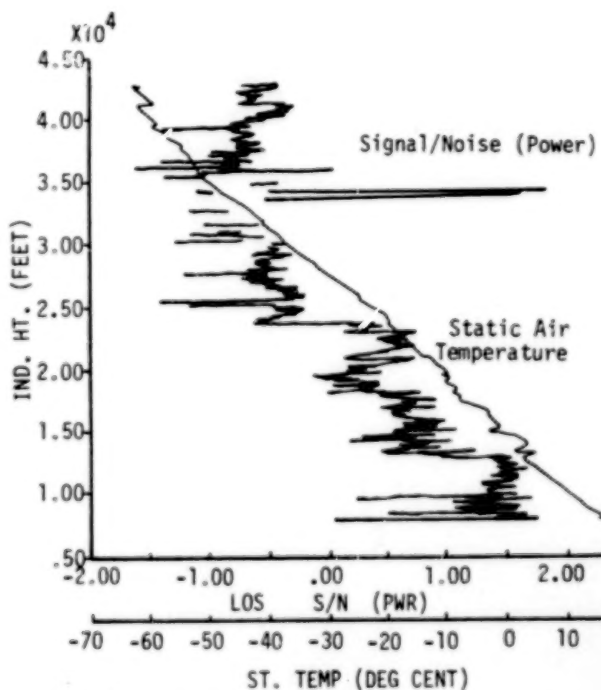


Figure 17. Example of Variations in Backscatter and Air Temperature With Height (RAE/RSRE LATAS)

The system also has uses for special test purposes. The data of Figure 17 can be converted directly into backscatter coefficient, and these data are needed to assist in the design and evaluation of proposed earth satellite laser

systems for global wind measurements. Another application is for accurate determination of static pressure errors on aircraft. The true static pressure can be calculated by measuring total pressure, which is usually unaffected by the aircraft flowfield, and total temperature, as well as the true airspeed ahead of the aircraft. This can be compared with the pressure measured by the aircraft static pressure system. The laser system could be mounted in place of a radar for these tests and frees the aircraft to obtain pressure error data under any flight conditions without ground based ranges, trailing cones or calibration aircraft.

The next stage of wind shear research with the LATAS system is to develop and test various laws and simple displays using a 2-pointer ASI and/or a Fast/Slow indicator on the ADI. These will be flown on the HS-125 and also assessed on larger aircraft in the RAE, Bedford, piloted flight simulator. So far the LATAS signals have been displayed only to the pilot on rudimentary meters mounted on the cockpit coaming.

### 3.0 VORTEX WAKES

Vortex wakes are another invisible hazard to aircraft, mainly during take-off and landing, although some encounters in cruise have also been found (REF 4).

The RAE has been actively involved in research in this field (REF 3,4,5 & 6), although no new experimental work has been done since 1977. That is, until recently, when two military accidents, one to a fighter and the other to a jet trainer, highlighted the need for methods of assessing hazard levels for a wider range of aircraft than the civil transport group. To support these studies, some further vortex wake measurements were made in flight using an RAE designed very fast response airflow sensor on the HS125. The sensor is a five hole conical yawmeter with surface mounted transducers and has a response time lag of about 1 millisecond. The response when enclosed in a balloon, which was then burst, is shown in Figure 18. The response is

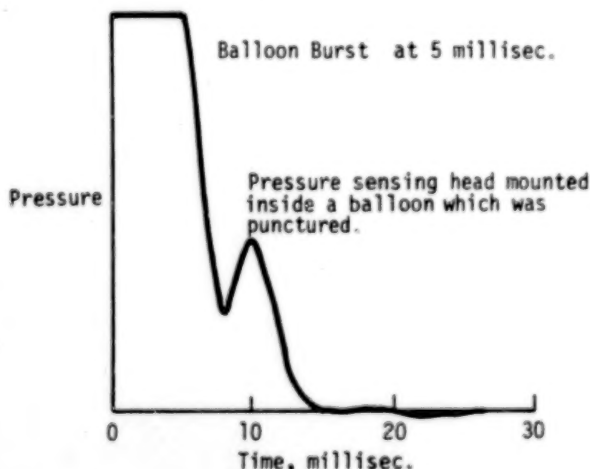


Figure 18. Response of the RAE 5-Hole Airflow Sensor To A Balloon Burst

so fast that the initial pressure resonances following the bursting of the balloon are clearly identified. An example of one of the vortex measurements is shown in Figure 19. The definition of the vortex structure with data at every 5 cm is quite remarkable.

Assessment of hazard levels needs three main inputs:

- Information on Vortex structure;
- A means of relating this structure to the roll control capability of the encountering aircraft;
- Criteria for acceptable roll disturbance.

#### 3.1 Vortex Structure

When trying to estimate the probable vortex induced velocities for advice to the accident investigators on the two military aircraft accidents, the author found two main difficulties. First the two most generally used relationships between tangential velocity, vorticity and radius were not very suitable and secondly there were difficulties in establishing the probable core radius, i.e., the radius to the peak tangential velocity.

The two most commonly used equations for vortex structure have been

$$V = \frac{(K/R)}{2\pi(r/R)} \left\{ 1 - e^{-1.256 (r/R)^2} \right\}$$

which was developed by Squires (REF 17 & 18), and

$$\frac{V}{V_c} = \frac{1}{(r/R)} \left\{ 1 + \ln (r/R) \right\}$$

from Kuhn and Nielson (REF 19),

where  $V$  = tangential velocity

$K$  = vorticity

$R$  = core radius

$r$  = radius

$V_c$  = maximum  $V$  (i.e., at core radius)

These two models are compared in Figure 20 at unit peak velocity. When compared with measured vortices, the Squires model contains more of the total vorticity inside the core and this results in a more rapid fall in velocity outside the core. However, the model does relate velocities to the total vorticity. The Kuhn and Nielson model is quite a good fit to experimental data around the core diameter and outside it, but unfortunately it is not related to total vorticity. Indeed at large distances from the core the vorticity tends to infinity. This is not a problem when fitting experimental data, but it does make it very difficult to use when estimating vortices from an initial

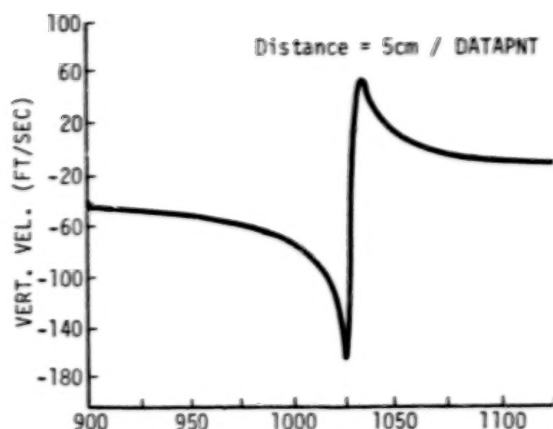


Figure 19. Flight Measurement of Vortex Velocity Using the RAE Fast Response Air Data Sensor

knowledge of total vorticity. The author has therefore developed a model (Figure 20) which matches the experimental data as well as the Kuhn and Nielson model and is related to total vorticity, viz

$$V = \frac{2(K/R)}{\pi^3(r/R)} \left\{ \tan^{-1} 1.392 (r/R) \right\}^2$$

Having defined a suitable formula, it is then necessary to derive values of total vorticity,  $K$ , and core radius,  $R$ , so that a velocity distribution can be defined. Various methods are discussed in REF 20. Except in rare cases, it is not worthwhile using the more sophisticated methods, and the author of this paper normally uses

$$K = P \left\{ L / (\rho b V_t) \right\}$$

where  $P$  = ratio of centreline lift per unit span

$L$  = total lift

$\rho$  = air density

$b$  = wing span

$V_t$  = aircraft true airspeed

$P$  is chosen as  $4/\pi$  ( $\approx 1.27$ ) for cruise configurations (elliptic lift distribution), or 2 for landing configurations (triangular lift distribution).

Estimation of radius is less well-defined as the growth depends strongly on the level of turbulence in and close to the vortex. However, the worst case is the slowest growth and experimental evidence (REF 21) suggests that Owen's formula, which is incorporated in Squires Vortex Formula and predicts growth proportional to the square root of vortex age, is reasonable up to the point where the two main vortices start to interact.

After this point, the experimental evidence (REF 22) suggests that the radius remains constant and the vorticity reduces linearly with time. (Actually, the vorticity is redistributed

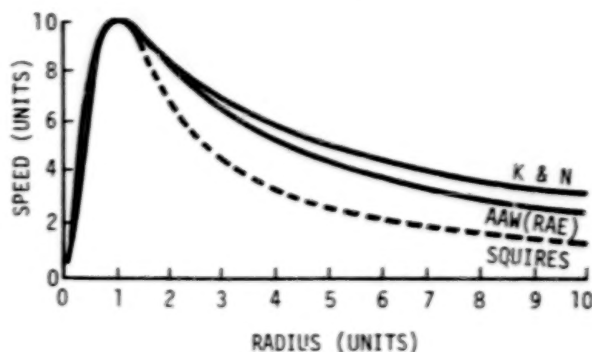


Figure 20. Comparison of Vortex Models

from the main vortices into small eddies.) REF 22 indicates that the changeover occurs when  $(d \text{ Lift Coefficient} / (b \text{ Aspect Ratio}))$  is 9.6. It may be coincidental that with the author's vortex formulae, this occurs when the total induced velocity at the point midway between the pair of vortices is equal to the tangential velocity at the core radius. The separation between the vortex centres is then about 9 vortex radii. Figure 21 shows the form of the three vortex models for twin vortices at this separation.

For typical civil transport aircraft on the approach, the changeover occurs at about 2-3 nm. Thus, normal separation requirements (REF 23), which are 3 nm or more, all relate to the region where the vorticity is decaying.

### 3.2 Vortex Strength

Vortex strength is a relative feature in the context of aircraft operations and is defined here as the ratio of vortex induced rolling moment to the maximum roll control moment of the encountering aircraft. Studies at the RAE

$$\text{VORTEX STRENGTH} = \frac{(K/D)g}{(P_{\text{MAX}} \cdot b)_e} f \left\{ \frac{b_e}{D}, \text{Taper} \right\}$$

where  $D$  = vortex diameter ( $= 2R$ )

$P_{\text{MAX}}$  = maximum roll rate suffices

$g$  = generating aircraft

$e$  = encountering aircraft

The size and shape function for the usual case of twin vortices (Figure 21) is found, Figure 23, to be only weakly dependent on  $b_e/D$  for aircraft of the same span as the generating aircraft ( $b/2R = 9$ ) down to about 20% of that span ( $b/2R = 1.8$ ), and for most normal values of taper ratio between 0.3 and 1.0.

Thus

$$\text{VORTEX STRENGTH} = (K/D)_g / (P_{MAX} b)_e$$

This can be evaluated using the vortex equations discussed in the previous section and the approximate relationship for transport aircraft (Figure 23) that

$$b_e \text{ (metres)} = \left\{ \frac{\text{MTOW}}{e} \right\}^{1/3}$$

and becomes

$$\text{VORTEX STRENGTH} = \left\{ \frac{WA}{\rho C_L} \right\}^{1/2} / \left\{ P_{MAX} \text{MTOW}^{1/3} \right\} / d$$

where MTOW - maximum takeoff weight

W - weight

A = aspect ratio

$C_L$  = lift coefficient

d = separation between aircraft

If a general rule for categorizing aircraft is required, then  $\rho C_L$  and  $P_{MAX}$  are approximately the same for most transport aircraft, and many long-range aircraft tend to have both a higher ratio of maximum take-off weight (MTOW) to maximum landing weight (MLW) and higher aspect ratio, A. Thus, the simplest relationship is

$$\text{VORTEX STRENGTH} = (\text{MTOW})_g^{1/2} / (\text{MTOW})_e^{1/3}$$

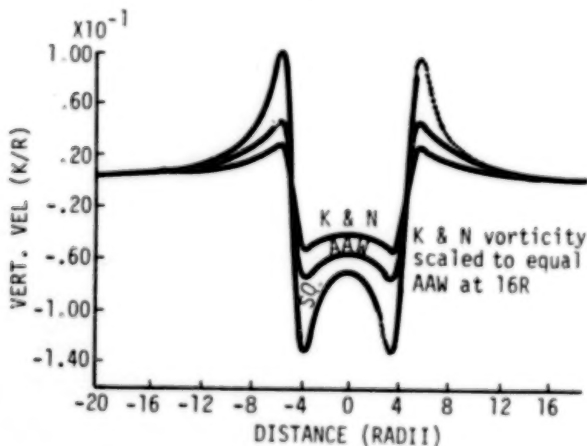


Figure 21. Twin Unit Vortices ( $K=R=1$ ) at 9R Separation.

The range of  $(\text{MTOW})_g / (\text{MTOW})_e$  are plotted against recommended separation distances in Figure 24 (a) for CAA and Figure 24 (b) for ICAO. The CAA recommendations are generally grouped in a way which agrees with the above weight relationship. Although it would seem that a weight

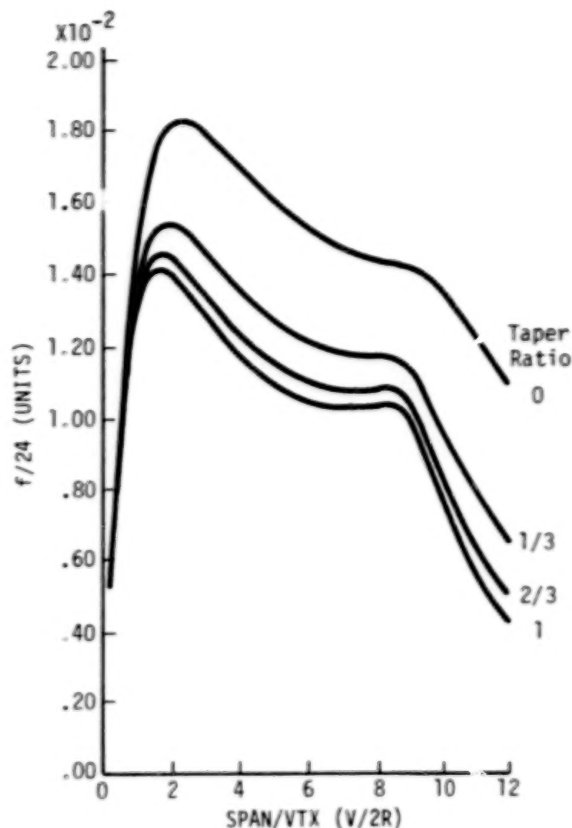


Figure 22. Vortex Strength: Size and Shape Function,  $f$ , at 9R Separation

grouping for aircraft below about 7000 kg would be useful especially for separation from the Heavy group. Also it looks as though the top of the Heavy group may be somewhere around the present maximum of about 380000 kg. The ICAO recommendations do not fit the weight relationship so well. In particular there are insufficient groups and the separation between the Heavy and Light groups would seem to be too low.

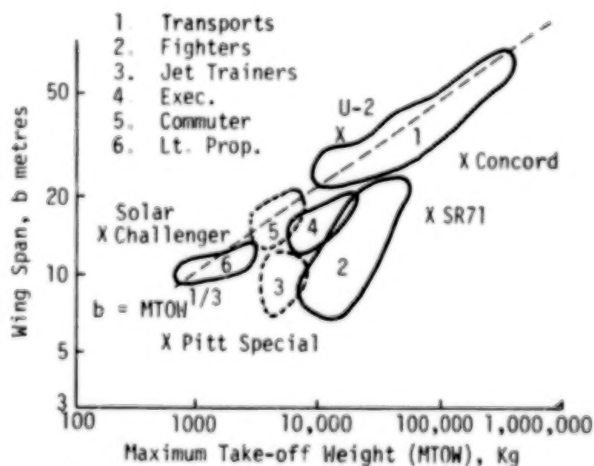


Figure 23. Aircraft Weights and Wing Span

### 3.3 Vortex Strength Criteria

The data of Figure 24 also gives indications of a possible relationship between Vortex Strength and Separation Distance. The CAA recommendations are based on practical experience of vortex wake encounters reported at London (Heathrow) over many years. REF 24 indicates the general philosophy, which is to reduce severe incidents to about 15 in 100,000 landings, which is expected to be equivalent to an accident rate of about 1 in  $10^7$  landings.

It is possible to work back from the relationship between separation distance and the weight factor to find the approximate value of Vortex Strength (i.e., ratio of induced rolling moment to roll control power) that the relationship implies. This is found to be about 0.7 for the CAA (or about 1.0 for ICAO) recommendations. The CAA criteria for a severe event is more than  $30^\circ$  of bank; thus, the equivalent for ICAO would be more than  $45^\circ$  of bank.

### 3.4 Discussion

The practical experience that led to the CAA recommendations for separation distances relate well to the theoretical estimates and show that the RAE estimation methods form a rational basis for assessing susceptibility to vortex induced roll. In general, it seems appropriate to categorize aircraft by MTOW as at present, and then use more detailed calculations to identify the few exceptions to the general groupings. An obvious example is Concorde, whose low aspect ratio would place it in a lower category than its weight would suggest. This is supported by the results of earlier tests by the RAE (REF 3), which showed that the Concorde wake did indeed decay much more rapidly than other transport aircraft.

Another conclusion from the theoretical equations is that military fighter and jet trainer aircraft are no less susceptible to vortex wakes than transport aircraft of the same weight. This

CATEGORY	WEIGHT (Kg.)
HEAVY	380,000*
MEDIUM	136,000
SMALL	40,000
LIGHT	17,000
	3,000**

\*approx. current maximum  
\*\*nominal minimum

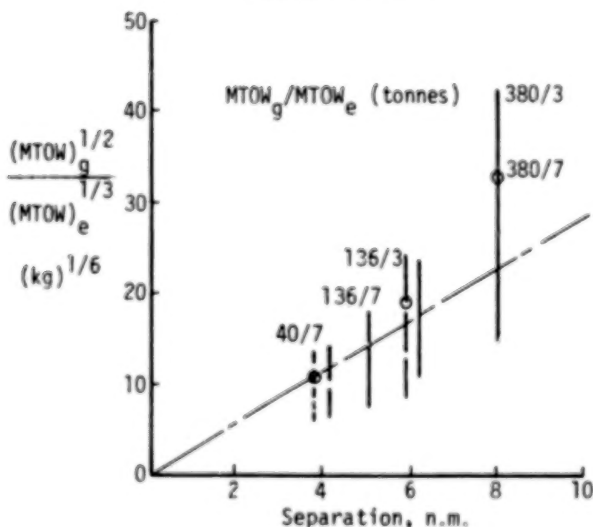


Figure 24 (a). UK CAA Separation Recommendations (AIC 81/1981)

CATEGORY	WEIGHT (Kg.)
HEAVY	380,000*
MEDIUM	136,000
	7,000
LIGHT	3,000**

\*approx. current maximum  
\*\*nominal minimum

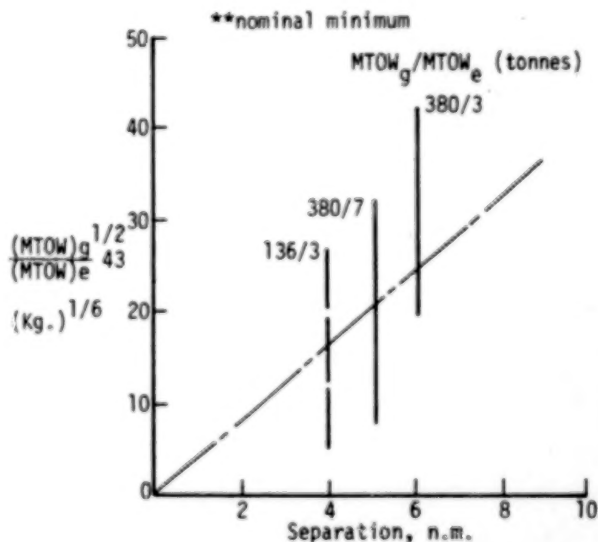


Figure 24 (b). ICAO Separation Recommendations (10 Aug. 1978)



has surprised most military pilots who felt that their extra manoeuvrability in roll would give them more protection. However, although the maximum roll rates on the approach are about twice as high as transport aircraft, the span of the military aircraft is about half. Thus, the critical term ( $b P_{MAX}$ ) is about the same.

## 4.0 BUILDING WAKES

Building wakes are related to both wind shear and vortex wakes. The increasing pressure to build on airport land to provide maintenance facilities for large aircraft and new terminals has produced situations such as the large airline engineering base alongside the final kilometre of the approach to runway 28R at London (Heathrow). Pilots landing on this runway are warned 'Turbulence likely below 300 ft near threshold 28R in strong S/SW winds'. This applies generally in winds of more than 15 kt.

The RAE are asked to advise the CAA on the acceptability of proposed new large buildings at many UK airports, but have been unable to give any positive guidance so far. There are basically two problems:

- a. a need for theoretical or model test methods to assess the character of the building turbulence, and
- b. relating turbulence characteristics to aircraft disturbances.

The second area is being addressed by the work to establish hazard levels for wind shear.

The first is the subject of joint research activities by Bristol University Aeronautical Engineering Department and the RAE. The first stage of the work showed that building wake turbulence in simulated natural turbulence can best be described as discrete eddies shed in a random fashion. The size and probability of encountering eddies being a function of the building, wind strength and natural turbulence. As the wind velocities are varying in space in a form that is related to the building geometry, it means that the frequently used Taylor's hypothesis cannot be applied. This hypothesis says that the distribution of velocities is the same if the observer is stationary and the wind brings the turbulence past him or if the observer moves through the turbulence (in an aircraft).

It was, therefore, decided that meaningful tests could only be made by traversing the wake of the building along a typical aircraft path and at the same order of speed. A series of such traverses would then allow the distribution of turbulence and the probability of encountering large disturbances to be determined. The main experiment is on a model of the Heathrow site in the Bristol University Building Research Wind Tunnel. This is being compared with a more limited set of data obtained from flights by the RAE HS125 at Heathrow. The Heathrow condi-

tions will also be used as a guide to levels of acceptability, as it would be undesirable to create any turbulence worse than the level at Heathrow.

The data from these experiments will be available in 1983 and it should then be possible to establish test methods and criteria for assessing proposals for large buildings at, or near, airports.

## 5.0 CONCLUDING REMARKS

This review of research in the UK on two of the more significant invisible enemies of aircraft, particularly during landing or take-off, has described the main features of the wind shear programme; the results from a recent vortex wake study, and the status of a study of airport building wakes.

The wind shear programme is aimed at providing relevant advice on aircraft certification implications, and developing suitable systems to provide information to pilots to make it possible for them to penetrate wind shear with safety. The three main elements of the programme are:

- a. Worldwide measurements of wind shear from regular airline flights and special trials with the RAE HS-125 research aircraft;
- b. Assessment of potential hazard to aircraft from wind shear;
- c. Development of systems to give the pilot information on wind shear.

These are expected to reach a point during 1983 when fundamental research will be sufficiently complete to provide the basis for certification and design of automatic control systems, such as autopilot, autothrottle, and autoland, and also for the development and production of wind shear detection and display systems. At this point, most of the RAE research effort will be transferred to other basic research tasks. The Establishment will continue to provide its usual consultancy service to the CAA and UK Industry.

The study of vortex wakes following the accidents to a military fighter and a jet trainer aircraft has led to the development by the RAE of a rational method for assessing the potential hazard for a given encounter, and also for categorizing aircraft into convenient groups. No further work is planned, although the recent study was unexpected. The study does highlight the benefits of flexible research facilities such as the HS125, which can respond rapidly to such unexpected needs.

The building wake programme is also reaching a point where it may be possible to establish criteria for acceptability, and corresponding test procedures for assessing new building proposals.

## REFERENCES

- (1) Pinsker, W. J. G., "The Assessment of the Potential Hazard of a Wind Shear Field Containing Horizontal and Vertical Draughts", RAE TR 78073 (July 1978).
- (2) Bisgood, P. L., J. W. Britton, H. Y. Ratcliffe, "Wind Shear Encounters During Visual Approaches at Night. A Piloted Simulator Study", RAE TR 79126 (Sept. 1979).
- (3) Bisgood, P. L., "A Brief Investigation in Flight of the Vortex Wake Generated by Concorde, with some Recommendations on Separation", RAE TR 78025 (Feb. 1978).
- (4) Pinsker, W. J. G., "The Hazards of Vortex Wake Encounters in the Cruise", RAE TR 79063 (June 1979).
- (5) Bisgood, P. L., "Some Observations of Condensation Trails", RAE Technical Memorandum FS 330 (April 1980).
- (6) Pinsker, W. J. G., "Further Observation on the Vortex Wake Hazard in Cruise Flight with Particular Reference to the Effects of Crow Instability", RAE TR 81069 (May 1981).
- (7) Woodfield, A. A., J. F. Woods, "Wind Shear from Head Wind Measurements on British Airways B-747-236 Aircraft - Initial Results", RAE Technical Memorandum FS 409 (June 1981).
- (8) Haynes, Ann, "Description of a Program Developed for the Analysis of Wind Shears Experienced During Aircraft Approach to Landing", RAE Technical Memorandum FS 321 (1980).
- (9) Jones, J. G., "The Application of Worst-Case Analysis to Aircraft Gust Response Assessment. A Statistical Discrete Gust Theory Progress Note", RAE Technical Memorandum FS 309 (1980).
- (10) Haverdings, H., "Statistical Analysis of Wind Shear Obtained from AIDS - Data Measured During Approach (Interim Report)", NLR TR 79095 (1979).
- (11) Haverdings, H., "AIDS-Derived Wind Shear Statistics for Approach and Landing. Influence of Ground Wind, Day/Night Effects and Search for Worst-Case Airports", NLR TR 81066 (1981).
- (12) Camp, Dennis W., Walter Frost, "Proceedings: Fifth Annual Workshop on Meteorological and Environmental Inputs to Aviation Systems", March 31 - April 2, 1981, UTSI, NASA CP-2192, pp91-95.
- (13) McCarthy, J., E. F. Blick, and R. R. Bensch, "Jet Transport Performance in Thunderstorm Wind Shear Conditions", NASA CR 3207 (1979).
- (14) Frost, W., B. S. Turkel, and J. McCarthy, "Simulation of Phugoid Excitation Due to Hazardous Wind Shear", AIAA-82-0215 (1982).
- (15) Vassie, C. D., D. M. Williams, "Wind Shear. The Vertical Speed/Energy Rate Indicator", Report by British Airways and Smiths Industries (1981).
- (16) Bullock, C., "Turbulence Detection by Laser", Interavia 1/1981, ppb.-83.
- (17) Squire, H. B., "The Growth of a Vortex in Turbulent Flow", ARC 16666 (1954).
- (18) Owen, P. R., "The Decay of a Turbulent Vortex", ARC 25-818 (1955).
- (19) Kuhn, G. D., J. W. Nielsen, "Analytical Studies of Aircraft Trailing Vortices", AIAA Paper No. 72-42 (1972).
- (20) Donaldson, C. Du. P., A. J. Bilanin, "Vortex Wakes of Conventional Aircraft", AGARD-AG-204 (1975).
- (21) "Aircraft Wake Vortices: A State-of-the-Art Review of the United States R & D Program", FAA-RD-77-23 (1977).
- (22) Hallock, J. N., "Vortex Advisory System Safety Analysis", Volume 1: Analytical Model, FAA-RD-78-68, 1 (1978).
- (23) CAA Air Information Circular 81/1981-1 December.
- (24) Piggott, B. A. M., J. A. Pask, "Wake Vortex Incidents Reported in the UK", 1972-76, CAA Paper 77012 (1977).

## **SECTION VI DINNER PRESENTATION**



## Joint Airport Weather Studies(JAWS) Project

John McCarthy  
National Center for Atmospheric Research

The Joint Airport Weather Studies (JAWS) Project is a joint program that is funded primarily by the National Science Foundation, which is the parent organization of the National Center for Atmospheric Research (NCAR). It is joint between the University of Chicago and NCAR; and there are three scientists that are the scientific investigators: Ted Fujita, Jim Wilson and myself; the latter two are from NCAR and Ted Fujita is from the University of Chicago. NASA, NOAA, and FAA have also contributed heavily to the project.

The major objectives of the JAWS Project are a fundamental description of the phenomenon, a determination of the hazard potential and a definition of a protection and warning system, all of which are relative to low-level wind shear. The focus of the entire project has been all aspects that we could address of the low-level wind shear phenomenon. The principal focus, however, has been the microburst. The microburst (Figure 1) is fundamentally a rather simple atmospheric flow. It is a downdraft that, upon approaching the surface, spreads out horizontally, producing what is called a diverging radial flow in all directions. Thus, for any direction that an aircraft flies through the microburst, it will first encounter increasing head winds; then the remnants of the downdraft; and then, increasing tail wind (Figure 2).

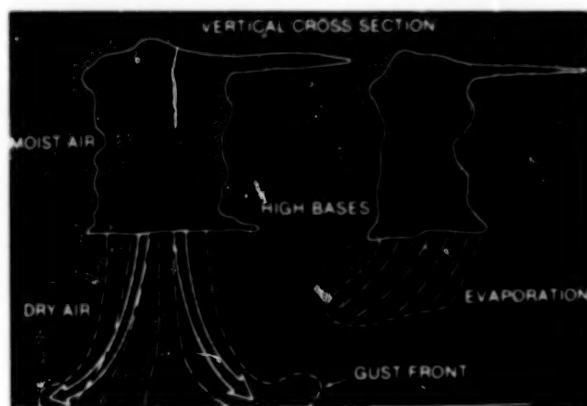


Figure 1.

The microburst feature, no doubt, has been around a long time. It was not identified, however, until the last few years. Probably about 1977, we had our first evidence of the existence of the microburst; but, because it is so small and short-lived, it has been a difficult feature to address scientifically and technologically. The focus of the JAWS Project has been to address that feature.

The location of our experiment was chosen to be the Stapleton International Airport in Denver, Colorado. Figure 3 is a picture of the airport



Figure 2.

taken from one of our research aircraft. It should be obvious, from this picture, that we were able to fly very closely around Stapleton Airport in many contexts. I would like to emphasize that the support we obtained from air traffic control to conduct this experiment was phenomenally good.



Figure 3.

Many observational tools were used in the experiment, but the principal observational tool was the Doppler radar. Doppler radar is a conventional weather radar with additional hardware that allows us to measure the velocity component of the atmosphere in a radial direction to the radar. It is the key to our observational system.

The blue dots on Figure 4 represent surface measurement systems which measured wind speed and direction, temperature, humidity, pressure and rainfall. Doppler radars were located at each point of the triangle shown in the figure. Basically, the entire area seen in the figure represents our research area, and it covers the northeastern quadrant of Denver.



Figure 4.

Figure 5 is simply a summary of what I will cover in this presentation of the JAWS Project: the microburst, a summary of data collection highlights; some impressions on low-level wind shear detection and warning, which is the major focus of our program; some analyses priorities and some recommendations and directions.

The JAWS Project has just ended its field phase. We have lots of data that have not yet been analyzed so that I am presenting impressions, not definitive results. Much analysis is needed to make those results concrete.

1. What is the Joint Airport Weather Studies Project
2. The Microburst
3. A Summary of Data Collection Highlights
4. Preliminary Impressions on Low-level Wind Shear
5. Analysis Priorities
6. Some Recommendations and Directions
7. Discussion

Figure 5. Summary of Presentation

Figure 6 shows the organizations that participated in this project. These were NCAR, the University of Chicago, and the Federal Government agencies shown in Figure 6b. The Universities which participated are shown in Figure 6c. We had a rather broad participation from the university community.

Figure 6d shows a very important and, frankly, a surprise addition to our program. This was the Royal Signals and Radar Establishment and Royal Aircraft Establishment from the United Kingdom. Most of the airborne wind shear detection warning concepts were flown on the aircraft supplied by this group.

The program had three components. Basic studies are ostensibly the National Science Foundation's concentration in the program. What is the microburst? What is its four-dimensional wind structure; the spatial and temporary dimensions? Where did it come from and what are the conditions that set up the existence of a microburst type feature? How long do they last? Why do they die? What is the relationship between small-scale and large-scale? These are very fundamental questions that the program addresses.

(a)  
OPERATORS

The National Center for Atmospheric Research  
The University of Chicago

(b)  
FEDERAL GOVERNMENT

National Science Foundation  
Federal Aviation Administration  
National Aeronautics and Space Administration  

- Marshall Space Flight Center
- Langley Air Research Center
- Dryden Flight Research Facility

National Oceanic and Atmospheric Administration  

- Prototype Regional Observing and Forecasting Service (PROFS)
- Wave Propagation Laboratory
- Office of Weather Research and Modification
- National Weather Service
- Research Flight Facility

Transportation Systems Center (Dept. of Transportation)  
Next Generation Radar (Depts. of Commerce, Defense, and Transportation)

(c)  
UNIVERSITIES

University of Chicago  
Massachusetts Institute of Technology  

- Department of Meteorology
- Lincoln Laboratory

University of Wyoming  
University of Tennessee Space Institute

(d)  
FOREIGN

Royal Signals and Radar Establishment,  
United Kingdom  
Royal Aircraft Establishment,  
United Kingdom

Figure 6. Organizations Participating in JAWS

A second major component of the program is aircraft performance. How do aircraft perform in the face of wind shear? (A lot of work went into this to clarify our thinking before we began the project.) Much of the interface between the atmosphere and aircraft performance was set up in discussions at the workshop on meteorological inputs to aviation systems held annually at the University of Tennessee Space Institute.



It was our intention when we set up the program, to have a very careful examination of flight data recorder from operational air carrier aircraft operating in the JAWS environment. However, we could not obtain the necessary funds. Thus, we did not study operational air carrier aircraft performance in the kind of quantitative detail that we wanted.

A third area of study was made by the Department of Transportation, Transportation Systems Center, on air traffic movements in the weather conditions that we faced in the JAWS Project. This work was done for FAA; it examined how the air carrier, air traffic flow was affected by not only wind shear, but the thunderstorm environment. Some very excellent data were obtained.

An extremely important part of JAWS is the detection and warning aspects. We have three surface sounding-type systems that we examined (or are in the process of examining). The output from the Low-Level Wind Shear Alert System (LLWSAS), which is currently at Stapleton, was recorded. It was through arrangements with FAA that we were able to record the data which, you know, is not normally recorded. The spacing of the LLWSAS between the center field station and the outlying station on the average at Stapleton is about six kilometers, a rather important number to remember; roughly 3.6 miles between the center field and the outlying station.

We had our own PAM (Portable Automated Mesonet) systems located where the blue dots are shown in Figure 4. Spacing between these wind recording stations was about three kilometers. Therefore, we had a system that was about twice as dense as the LLWSAS at the Denver airport.

Finally, we had a pressure jump array system developed by the NOAA Wave Propagation Laboratory, which essentially looks at rapid surface pressure fluctuations as a means of identifying wind shear.

All airborne systems flown were on the Hawker-Siddeley 125 from England; we had a really excellent platform from England. The air speed and ground speed procedure developed by FAA was flown on this aircraft. The aircraft had a forward-looking Doppler lidar that looked out the nose of the aircraft and measured the longitudinal component of wind ahead of the airplane with about six seconds lead time. Finally, it had a Smith's Industry's vertical velocity energy rate system, which is fundamentally an accelerator concept that allows the pilot to understand that he is in a wind shear situation.

A number of Doppler radars were used at the center field of Stapleton Airport looking in all directions. Most of the time they were looking up the approach and departure corridors, measuring the head wind/tail wind component to or from the airport. We also had what I consider the NEXRAD concept. NEXRAD stands for the Next Generation Radar program. It is a joint program between NOAA, FAA and the Department of Defense to Dopplerize the national weather radar system in this country. NEXRAD

addresses many applications of Doppler radar in an area-wide mode and it also addresses wind shear explicitly. Finally, at the airport center, we had a NASA Doppler Lidar (Lidar is a laser system as opposed to a pulse microwave radar system), which measures the longitudinal components of the wind.

The Doppler radars in the JAWS Project are located as shown in Figure 4. Figure 7 shows our main radar control center with the front range of Colorado in the background. The interior of our control center is shown in Figure 8. Our entire operation was run from this center. It was a tremendous center. Some of you visited it. It was a very impressive control center where the aircraft and the complete operations were directed.



Figure 7.



Figure 8.

Figure 9 is a picture of our five centimeter Doppler radar located at Stapleton Airport with another example of one of several thunderstorms and electric storms that occurred in the vicinity of the airport. The terminal building is in the immediate background.

In terms of lidars, we also had the NASA lidar at CP-4 and a NOAA lidar at CP-3. As I mentioned, we also had an airborne lidar on the HS-125. Figure 10 shows the HS-125 with a wind probe on the nose. The lidar looks out ahead of the aircraft at all times and gives you about a four-second lead of what the winds are going

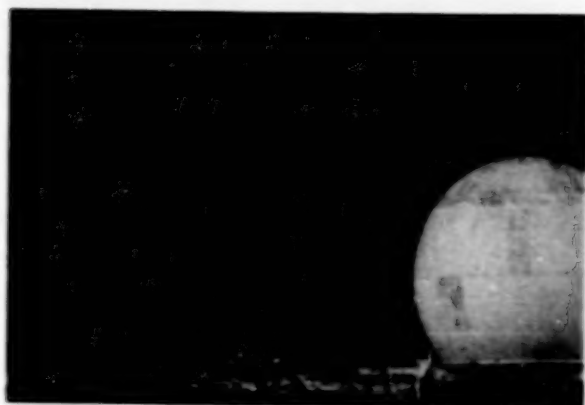


Figure 9.

to be when you get there. The forward-looking lidar, basically, gives you a few seconds of advanced notice as you go through a rapidly increasing head wind, downdraft and tail wind. We think it is an interesting system when it is coupled with the air speed and ground speed concept because it allows us to address wind shear with a slight lead time. Lead time on approach would represent about two-thirds of the spool-up time required if you were to encounter a sudden wind shear. Therefore, it is an exciting system.

In its current configuration, the system does not work on takeoffs. There is no question that it certainly will operate, but I think its usefulness is obviously less on takeoff mode than on landing mode. I think that the airborne systems are basically designed for approach rather than departure. However, there has been quite a bit of discussion about trying to develop a forward-looking Lidar that has scanning capabilities and considerably greater range. It is a concept that we ought to pursue. If you extend the range and give it some scanning capabilities, then it would be a viable system on takeoff as well.



Figure 10.

Lasers are, of course, subject to attenuation, particularly if they are CO<sub>2</sub> lasers and operate in the visible range. It does not penetrate into cloud; but it has a rather excellent ability to penetrate some distance into precipi-

tation, including heavy precipitation. Therefore, I think in the wind shear context, it is really a very viable system. If it is foggy or cloudy, it is not viable; so that is a limitation.

The lidar, like the radar, will work in clear air because, in fact, the air is not clear. There is dust and there are all kinds of scatters out there, particularly at the low levels. If you get up in the high altitude, it doesn't work because the air is clean. However, in the airport environment, there is no problem seeing the wind with a laser.

The HS-125 also had a Smiths Industry system, which is basically an accelerometer system. If you get an upward acceleration difference, it implies a head wind increase, and there is a transition until you get a sudden downward acceleration, which implies a tail wind. It is an inferred system; it is not dissimilar in concept with the Safe Flight type system and I will make some comments on all of these systems a little bit later on.

I have already mentioned the surface observation systems which are portable and automated. NCAR has 27 such stations. A PAM system, located near Stapleton, is shown in Figure 11.

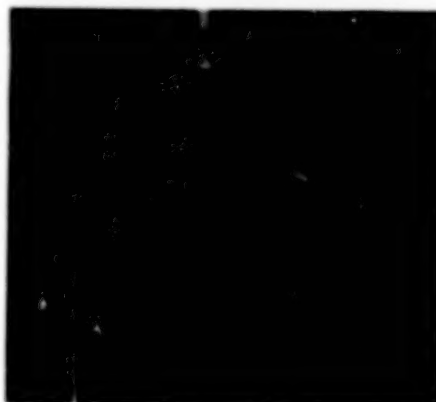


Figure 11.

In terms of aircraft, we had the research King Air from the University of Wyoming; the NCAR Sabreliner; and the NASA B-57, which carried out a gust gradient experiment during JAWS. We also had the NOAA P-3 aircraft primarily to test an airborne Doppler radar. The King Air aircraft is shown in Figure 12. We had very high resolution air motion sensing on it as well as some excellent cloud physics instrumentation to study precipitation; precipitation rates in the downdraft, which are important in the heavy rain kinds of studies as well as in the evolution of the downdraft in precipitation. This is a very important part of the project.

During the project, we had lots of heavy rain. We had a number of cases where the reflectivity values were in excess of 70 DB. Of course, that is probably hail contaminated in terms of the reflectivity. We had many cases of strong wind shear in heavy rain. An important part of that

study with the King Air aircraft is that by measuring the precipitation spectrum in great detail, we will be able to determine the negative buoyancy associated with precipitation loading in the precipitation shaft and to understand why the downdraft occurs and why it is so strong.

The NASA B-57 was in the project to study gust gradients. It had a gust probe on each wing tip, and a gust probe on the nose. The gust gradient program is designed to study turbulence and wind shear, not only in the longitudinal sense, as the aircraft flies, but also in the latitudinal cross-spanwise sense. This is a very important basic study.



Figure 12.

The NOAA P-3 had an airborne Doppler radar that got some outstanding results in microbursts. We were able to look down, right down through the center of a microburst on the 29th of June and collect data on the vertical velocity right down to the surface.

Without getting too far into the technical details, I would like to say that one of the things we are trying to do in the JAWS Project is to take Doppler radar from three ground Dopplers. Remember now, that a single Doppler radar gives you only the radial component. So, if we want to reconstruct the three-dimensional wind field, we have to look at it from three different directions. We have rarely had the opportunity to look straight up through a microburst because they are so small and don't last very long. Therefore, we have to infer through the equation of continuity what the vertical velocity structure will be. That is a viable thing to do. However, what we have with the P-3 airborne Doppler is a measure of direct vertical incidence all the way through a microburst. Now we are able to understand the shape function of how the vertical draft converts to a horizontal draft from direct measurement. It is very important, scientifically and technique-wise, to analyze this data set.

I want to now spend a few minutes on describing the microburst. The microburst is a downdraft. We have known about downdrafts for a long time. As a matter of fact, when I was in Washington 1 1/2 weeks, an employee of NSF told me about a

sketch done in about 1650 in England of something that closely resembles a microburst. Thus, people have seen things like microbursts for a long time. It is downdraft in its basic form. When it approaches the ground, it spreads out horizontally. The microburst is defined as a downdraft and outflow, which is no bigger than 4 kilometers or 2.4 miles, horizontally. It is very small, compared to a large supercell, severe thunderstorm. In Denver, we encountered two types...one that was associated with the large thunderstorm, and another that seemed to occur in very benign-looking clouds. These may appear very weakly on our standard weather radar and look benign from a distance; but, in fact, they can produce very strong flows near the surface.

As far as any relationship between the amount of rain that is measured at the surface and the intensity of wind, we think there is no correlation. The reason I say that is because if we have low-level wind shear in a microburst context, it appeared to be just as likely to occur in a little or no-rain situation, as it did in a very heavy rain situation. This suggests that reflectivity measured by ground-based radars, as well as airborne radars, has no correlation between storm intensity and wind shear. This, we believe, is exactly right in the microburst context. The larger and more severe the thunderstorm, the more likely it will be to produce a gust front, which is a large-scale system. However, in terms of the microburst, i.e., the small-scale wind shear event, it appears to us, in a preliminary sense, that it is uncorrelated; a very significant result in our opinion.

Again, referring to Figure 2, why we think a microburst is such an insidious wind shear event is that it is a downdraft and radial outflow. It is very small and rather symmetric; like a jet of water from a hose directed towards the surface of the ground, it spreads out in all directions.

If you fly through a microburst with an airplane, you get the same thing every time, in a conceptual sense. You get a rapidly-increasing head wind, which suddenly changes to a rapidly-increasing tail wind. When you cross through the center, you encounter the remnant of the downdraft.

The problem with the microburst, as we see it, based on some of the aircraft performance studies we have done, is that you get a rapidly-increasing head wind when you first encounter a microburst. This is good news, resulting in increased lift, but decreased airspeed. However, the head wind suddenly changes rapidly to a tail wind, killing the aerodynamic lift.

I believe that approximately 80 percent of the problem with wind shear is loss of lift due to the decaying wind speed horizontal component. The downdraft and what is left of it is certainly not helping the aircraft. It is acting in the wrong direction, downward.

Now, let me contrast the microburst flow from that of a gust front. I think this is very important. Figure 13 is a picture of a gust front. A gust front is produced by a downdraft and outflow, but the outflow has become very large-scale. It may be a front, or like a cold front that stretches out ahead of a thunderstorm for many, many kilometers. Figure 16 is a picture of a cross-section through a gust front. A gust front flows outward from a thunderstorm into quiescent air; thus, cold air flows over the ground while warm moist air flows up into the thunderstorm. The flow is fundamentally a converging phenomenon; that is, cold air is impacting warm air. If you fly through a gust front at low levels, as illustrated in Figure 14, you may have a little lift loss in the warm air accelerating over the cold air; but, as soon as you penetrate the gust front, you get a lift increase because you are entering a rapidly-increasing head wind.

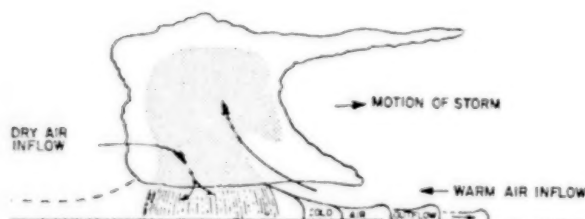


Figure 2.1 Typical thunderstorm cross section (schematic) [22].

Figure 13.

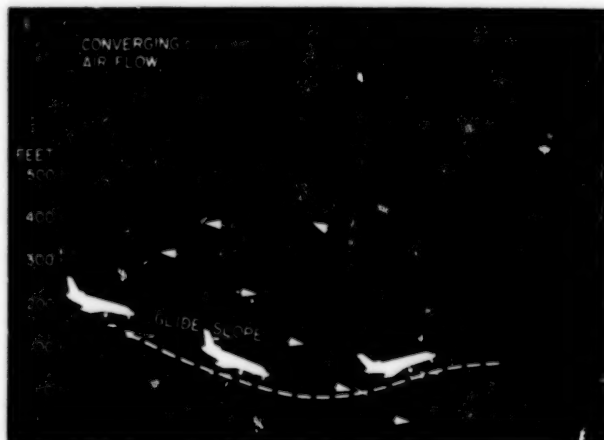


Figure 14.

Penetrating a gust front, in my opinion, is an energy builder for the aircraft, but a microburst is an energy loser. That is, in a diverging outflow (microburst), you tend to lose lift as you penetrate it; but a gust front, in a general sense, is probably an energy gainer.

This is significant because five years ago, we thought the gust front was the name of the game. We thought in the research community that a gust

front was the killer in aircraft accidents. We did a lot of work in that area. A lot of work was done at NSSL, and gust fronts were considered to be really a very serious situation. However, it is our opinion in the JAWS Project that the gust front is a larger-scale feature that probably is not the killer in the generic sense. So, we are actually now concentrating on a much smaller scale, that we think is important. I'm not saying, of course, that gust fronts are not an aviation hazard; but there is an evolution in our thinking. We are beginning to believe that the aviation hazard is more associated with a small-scale event than a gust front. I'm not recommending flying through gust fronts. There are some hazardous features in gust fronts. They are turbulent. We think there have been several accidents associated with the turbulence in gust fronts.

Figure 15 is a composite picture of a dry microburst situation over Stapleton Airport. Frequently, a 50-, 60-, 70-knot differential at the surface can occur with this kind of feature. This is an important picture because it shows what a dry microburst can look like. They don't look too serious with the eyeball, but it is a visual clue. Don't fly through virga shafts, i.e., something like that illustrated in the picture at Denver, when you are on immediate approach or takeoff. On one day, we had an 80-knot differential on the north-south runway in Stapleton for this kind of situation (Figure 15); dry, reflectivity values from radar about Level 2. You fly through this situation and get a few drops of rain on the windshield; but you get tremendous wind shears.

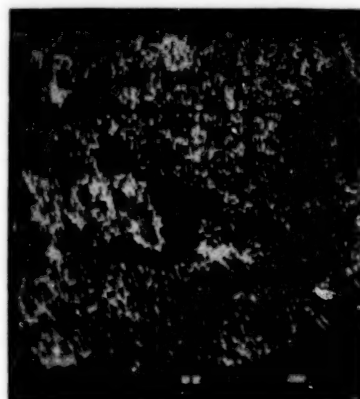


Figure 15.

Figure 16 is a good picture of what a dry microburst looks like from the air. In this picture, a microburst has hit the ground and is spreading out horizontally, creating a ring of dust. The ring goes all the way around the back side, although the picture does not show it terribly well. If you see such a dust ring when you are sitting on the runway or on approach, we recommend that you do not fly through it. It may be a visual clue to a very severe wind shear condition. We don't have a picture of it, but a pilot reported seeing the trees blowing out radially when looking down on approach to



Stapleton. This indicates the wind was blowing out in all directions.



Figure 16.

The important point from this discussion is that there are certain visual clues that are associated with the microburst. We are recommending to FAA that they produce a revised information film to address the visual clues of microbursts, the simulator aspects of microbursts, and finally, the radar aspects of microbursts. These are some of the things we think can help; and one of the first things we can do with JAWS results is to put out a revised information film that gets to the core of the issue and helps raise visual consciousness of the phenomenon.

Now, I would like to show you what a microburst observed during the JAWS Project this summer looks like on Doppler radar. Figure 17 is a photograph of the Doppler radar scope. The radar is located to the right at the point where the horizontal lines converge. The circular lines are spaced at 10 kilometers. The line farthest to the right is 20 kilometers from the radar. Figure 17 is at zero degrees elevation, such that we are looking just above the surface about 28 kilometers away from the radar. The colors represent the magnitude of the Doppler velocities according to the color code given at the bottom of the figure. Only the component of velocity towards or away from the radar is displayed; that is all you can measure with a single Doppler radar. The figure shows a down-

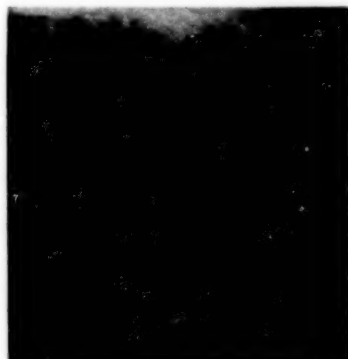


Figure 17.

draft which has reached the surface and has spread out in all directions horizontally, but remember, we can only see the component towards or away from the radar.

The green biological tones represent air moving towards the radar and the browns represent air moving away from the radar. Every color change in the color coding represents 5 knots of increase or decrease in wind speed. Now, consider the evolution of the microburst as a function of time.

Figures 18 a - f are a sequence of pictures of the same microburst as it evolves in time. The time of the first picture, Figure 18a, is 1641 local time, on the 14th of July. At this time, the low-level velocities are benign. Each color change represents 5 knots, so there is 15 knots of velocity represented; no significant microburst features. Figure 18b is two minutes later. We now have the beginning of what we call a diverging outflow, as seen by Doppler radar with air moving away and air moving towards the radar, as indicated by the changing colors. A microburst has hit the ground and has begun to spread out. There are now five (5) different color changes shown on this diverging outflow; five times five is 25 knots...not a particularly serious situation yet. Note the total dimension from maximum head wind to maximum tail wind is slightly less than 2 kilometers. Three minutes later (Figure

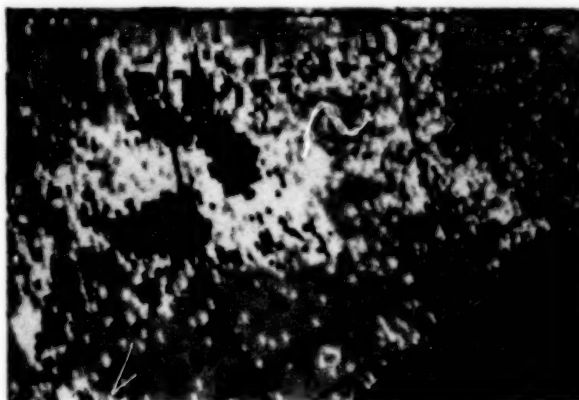


Figure 18a.

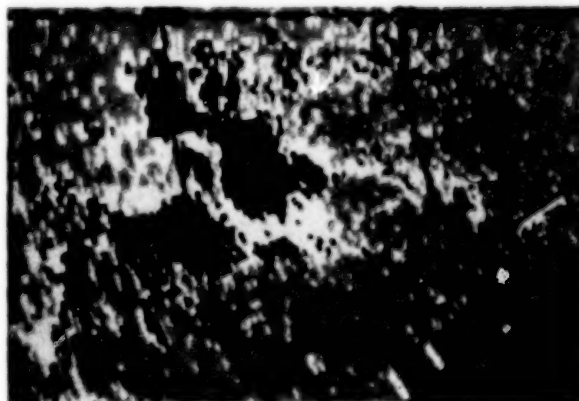


Figure 18b.



18c) there are eight color changes, i.e., 40-knot differential across roughly the same 2 kilometers, a very small feature. The time at the top of the figure is now 1646. Five minutes previously there was nothing in terms of wind shear.

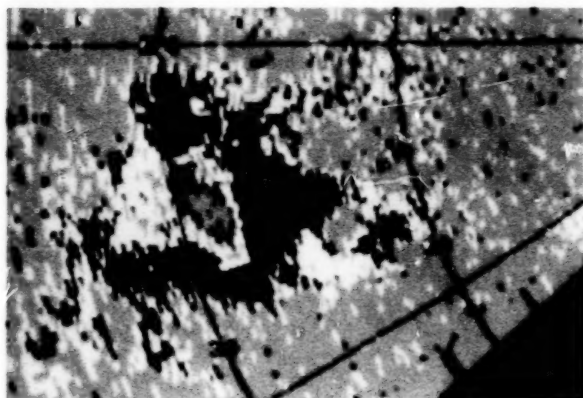


Figure 18c.

Figure 18d is at time 1648; we are now 7 minutes from when there was nothing and we have reached the maximum velocity differential. Eleven different color codes; 55-knot differential. The

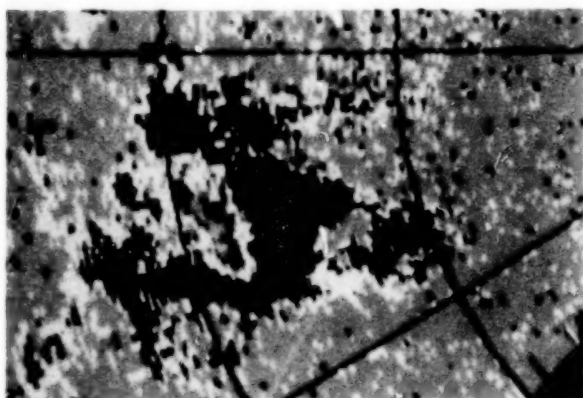


Figure 18d.

feature is about 2-1/2 kilometers from peak to peak. Figure 18e, photographed another 2 minutes later, shows the microburst is falling apart rapidly; it is spread out; the distance between peak velocities is about 5 to 6 kilometers. Figure 18f, the last picture, is 52 past the hour and shows the same kind of wind speed we had in the beginning (Figure 18a). The microburst is gone. The entire evolution of the microburst was about 6 minutes. It never got bigger than about 2-1/2 or 3 kilometers in its most intense form.

At Stapleton, the spacing between the LLWSAS field anemometer and the outlying station anemometer is 6 kilometers. A LLWSAS is not going to see such a small feature.

Commonly, microbursts are 1 to 3 kilometers in maximum dimension, when at their maximum inten-

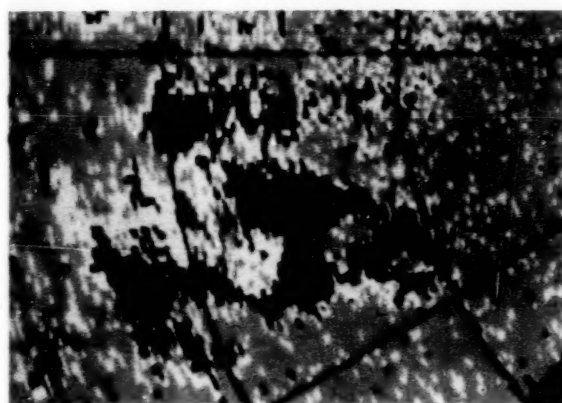


Figure 18e.

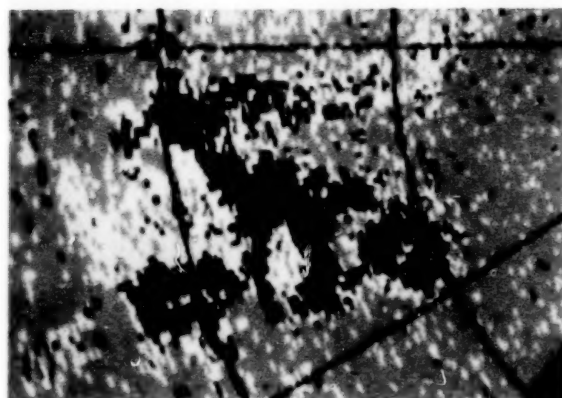


Figure 18f.

sity. When they hit the ground, they accelerate and then die. They are very small and they don't last very long.

We didn't know about microbursts a few years ago. We began to surmise their existence after Eastern 66, Continental 426 and a number of other aircraft accidents; but we didn't have a handle on the short-time scale, the intensity and the small spatial dimension.

If you look at the microburst in the vertical direction at its time of maximum intensity (48 past the hour), it fades fast above 900 feet. At approximately 500 meters above the ground, or at an outer marker height, there is no sign of the microburst on the radar. This is what you would expect because it is a surface feature. It hits the ground and spreads out. It is a downdraft that converts into a horizontal flow close to the ground. (Note: downdrafts are not seen on a single Doppler radar.)

We have just looked at one record of a microburst measured during the JAWS Project. We have an immense amount of other recordings and data as indicated in Figure 19. The JAWS Project consisted of 91 possible operational days (from the 15th of May to the 13th of August). Of that total, we had only 16 days where there was no convective weather.

	Number of Events
Microbursts (<4 km)	62
Microbursts in Good Dual Doppler Coverage	54
Downbursts (>4 km)	14
Virga but No Outflow (null cases)	18
Gust Fronts	35
Mesocyclones	20
Tornadoes	7
Funnel Clouds	2

Figure 19. JAWS Data Collection Highlights

We had expected, when we began the project, to get maybe 25 microbursts this summer. We got 62 microbursts, i.e., diverging outflows less than 4 kilometers in horizontal dimension. Ten or 12 of these microbursts were measured with dual Doppler radars. (Dual Doppler allows us to reconstruct the velocity structure in three dimensions.) We got 54 downbursts in dual Doppler, which are distinguished from microbursts because the outflow is greater than 4 kilometers in extent.

We believe, from the aircraft performance work, that if the outflow region becomes larger than about 4 kilometers, it is probably less likely to be severe in terms of aircraft performance. So, we think that the microburst is the feature of most interest in an aviation context.

Virga is the precipitation coming down towards the ground, but not reaching the ground. What happens to virga is that it evaporates and, of course, in the evaporation process, it cools and causes the downdraft to accelerate. We had 18 cases where we had downdraft air approaching the surface in which it seemed like a microburst may have formed, but need not. Therefore, virga didn't always cause a microburst.

Of the 62 microbursts, about 60 percent occurred in the non-thunderstorm situation; that is, low-level reflectivities, no lightning; not a thunderstorm, by definition. The other 40 percent occurred imbedded in thunderstorms where there were rain, lightning, and all the properties of a thunderstorm. Thus, both types of microbursts were observed.

Data were collected on 35 gust fronts, which is about 10 years of gust front data collected from the National Severe Storms Laboratory (NSSL) in Oklahoma. There was a phenomenal amount of weather this summer.

Twenty mesocyclones, which are the parent circulations of tornadoes, and 7 tornadoes occurred for which we collected data. This was not a JAWS objective, but we couldn't resist working it. Nine hailstorms occurred that dropped hail on the radar, which is a pretty phenomenal statistic considering how close our radars were to one another. Another factor which has a bearing

on these discussions is nowcasting applications of Doppler radar. With Doppler radar, we were able to see many features at low levels that allowed us to make a nowcast as to where thunderstorms would form. This is a very exciting use of Doppler radar in the aviation context, and these data were sent to the FAA's Center Weather Service Unit in real-time. The tremendous viability of Doppler radar is thus demonstrated in the aviation system context; not in the wind shear sense, but in using Doppler to identify the formation of hazards for use in changing the airspace flow, etc.

Figure 20 lists detection and warning systems for which I will give you some impressions, and these are only impressions, on what we came up with this summer. The LLWSAS at Stapleton had a spacing that was too large to capture the microburst feature on a regular basis. The LLWSAS did see diverging outflows but only after they became large enough to reach the scale for which the system was capable of responding. The NCAR system, which is on a density twice as great as the LLWSAS, was correspondingly more successful in seeing the microburst because the spacing was 3 kilometers.

- Airborne Systems
  - Airspeed and Groundspeed Procedure
  - Forward-looking LIDAR
  - Vertical Velocity/Energy Rate
- Doppler Radar
  - Airport Approach and Departure Corridors
  - Area-wide NEXRAD Concept
  - Doppler LIDAR at Airport Center
- Surface Sensors
  - Low-level Wind Shear Alert System
  - NCAR Portable Automated Mesonetwork
  - Pressure Jump Array

Figure 20. Detection and Warning

It is a preliminary, but, I think, logical, conclusion that the LLWSAS system in its current dimension is really not addressing the scales of motion which are of concern in the JAWS Project. I think the low-level wind shear alert system was put together at a time when we thought the gust front was the name of the game in terms of the severe hazard. Therefore, I think we need to address making the system better, and you can do that by increasing the number of stations; or, possibly, a number of other things can be done.

We have not yet addressed the pressure jump rate data. At present, I have only the results of verbal conversation with the British HS-125 crew relative to airborne systems. Their comments are, "Very exciting data; the best data we have ever seen in wind shear." The sound quantitative results, however, remain to be seen.

Doppler radar proved to be astoundingly successful in seeing the wind shear, both in dry and wet cases. I think the NEXRAD system, if the radars are placed near the airport, will give very exciting results. It is preliminary, but if you want to cover an airport environment, the Doppler radar does a very fine job. A conventional radar, or a weather channel on the surveillance radars, will not measure wind shear.

Figure 21 lists the analysis priorities. The wind shear profiles used in simulation and manned-flight simulators are not adequate. They do not address the scales of motion that we are looking at in the JAWS Project. The current systems, therefore, do not address worse-case conditions found in the four-dimensional structure of the microburst from the JAWS Project. These data need to be provided to the simulator world, not only for proficiency and training, but in testing of airborne systems. The analyzed data should be added to FAA Circular 120. Analyses of the data is a high priority of the JAWS Project.

- Preparation of High Resolution 4-Dimensional Microburst Profiles for Improved Manned-Flight Simulation
- Establish Microburst Frequency Distribution
- Quantitative Ordering of Detection and Warning Critical Success Ratio
- Training Film for Pilots Describing Microburst Hazard and Providing Visual Clues
- Quantification of Wind Shear Severity Using JAWS Data Set
- Doppler Radar Siting to Establish Suitable Detection Range as a Function of Hazard
- Research Versus Training Simulation Response to Microburst Wind Shear Profiles
- Close Analysis Relationship with United Kingdom Royal Aircraft Establishment
- Development of Prototype Airport Doppler Concept for Wind Shear and Other Terminal Hazard Detection and Warning

Figure 21. Analysis Priorities

We didn't expect to measure enough microbursts to establish a microburst frequency distribution. However, we have enough data from the JAWS Project to do that for Stapleton. What is the frequency distribution? We had lots of microbursts with velocities 50 knots or greater. Why do airplanes not crash all the time? The answer to that, in our opinion, is that the space time window for a microburst is extremely small. You have to encounter it below 500 feet. Moreover, since it is very small in spatial dimension and

doesn't last very long, you have to be in the wrong place at the wrong time in order to be in trouble. Thus, even though they are fairly common in summer, the probability of a microburst being over the runway in exact coincidence with an aircraft landing or departure is a very rare event.

All of the detection and warning systems tested will be quantified as to their detection and warning capability. I have given you impressions which we will analyze quantitatively. An updated information film is needed this year and a newly updated film the year after. Pilots and controllers need to view this film to keep the consciousness alive as to how serious a wind shear event is and how to deal with it.

How severe is severe? We have data that we will use in simulator studies, in modeling studies in the analysis phase. The data from JAWS will be used in research simulators such as NASA Ames, NASA Langley, and elsewhere, to measure "How severe is severe?" I think that aircraft are going to fly in wind shear for a long time. We are not going to keep airplanes out of wind shear. Wind shear is all around us all the time. The question is one of accurate and timely detection of wind shear that can cause accidents. We have the data to get to the bottom of that problem, which is what we plan to do.

Doppler radar siting as a function of range needs to be resolved. If the Doppler radar is sited too far away, you cannot see the microburst because when it's right on the surface, it is lost in the earth's curvature. Thus, siting is an important issue relative to NEXRAD.

It is our opinion that the research simulators do a pretty good job of simulating wind shear in the microburst scale, but we're not sure this is the case for training simulators. For reasons which we are not certain of yet, we believe there is a lack of response to the wind shear profile in the training simulator. They either under-damp or over-damp the response to head wind, tail wind, or downdraft on the scale of a few seconds where microbursts wind shear is critical.

Finally, we are going to work closely with the United Kingdom Aircraft Wind Shear Program, and we may be addressing the issue with FAA about the next stage of a prototype system for Doppler radar.

As the final part of this presentation, I am going to give some impressions. Microbursts are common in Denver. We didn't do a research program elsewhere. We did one in Chicago in 1978, and there were quite a few microbursts; but the program was not designed as it was in Denver to adequately address the scale. I think microbursts are rather common. I think if you go east and south from Denver, you are more likely to find microbursts imbedded in thunderstorms and less likely to have the dry microbursts that you have in the west. Wind shear problems in Tucson, El Paso and Denver

have been more related to the dry case. If you go east and south, to New York and Philadelphia, you are more likely to encounter the thunderstorm-imbedded microburst.

The question arises as to whether you can apply JAWS results in regions other than Denver. From the fundamental physics perspective, we always worry about that kind of problem. However, from the warning and detection operations point of view, I think the answer is yes. The microburst flowfield which causes accidents will have the same kinematic form near the ground in Florida as it does in Denver.

We have a lot of data on microbursts. We know now that they are small, short-lived and can be intensely lethal. Thus, microburst detection is very important in aviation safety.

The low-level wind shear alert system in its current form, we feel, is inadequate. We have no question that it was a proper decision to install this system. At that time, the gust front was thought to be the culprit, and this system is a great gust front detector.

Our technology and our awareness of the atmosphere has concentrated a lot of attention on the need for new systems and new approaches. A lot of work has been done by FAA. It is outstanding work. For some reason, results of this work were not implemented. We need to think about implementing airborne systems in a more rigorous way. We need to look at Doppler radar and we may be able to address the low-level wind shear alert system problem by increasing the number of anemometer stations.

I am a tremendous proponent of the airborne systems. You cannot have a low-level wind shear alert system or Doppler radar at every airport because the money isn't available. An airborne system goes with the airplane, so that is an obvious advantage. The air speed and ground speed system, I think, is a good system because ground-speed flying makes sense. There is, however, some disadvantages of the ground speed/air speed concept. Eventually, for example, it will encourage you to fly through a wind shear and one of these days you will go into a wind shear that exceeds the capability of the aircraft. So, any system that requires you to enter the wind shear before you can detect it has a problem in concept.

The current airborne systems as they are now construed are useful only on approach; and takeoff accidents are not covered. There is, however, more research that can be done to help improve this part of the situation.

The airport Doppler concept, I think, is a great idea. It costs money. In a warning and detection system, whether it's the Doppler radar or any other system, time is critical. The wind shear signal will live and die in a few minutes. This information must be related to the cockpit immediately. It can be uplinked. The technology exists to uplink the data. Uplink of wind shear information is an issue with which we need to be dealing. Also, the issue of how we decide to fly or not to fly in a certain situation, is a big issue. Thus, there are still many unresolved problems. The JAWS Project has provided a goldmine of data to address the issues. Thus, we believe that we are at the threshold of making a quantum step forward in resolving the wind shear problem.



# SECTION VII COMMITTEE SUMMARY REPORTS





# COMMITTEE SUMMARY REPORTS CONT.



## SUMMARY REPORT: Training/Simulation Facilities Committee

Members: Ted Mallory, Chairman, Director, Flight Standards & Training, Republic Airlines

Roland L. Bowles, Aerospace Technologist, NASA/Langley Research Center

Iris C. Critchell, Director of Aeronautics Program, Harvey Mudd College

Keith A. Hill, Flight Simulation Applications, Boeing Computer Services

Dale W. Istwan, Air Line Pilots Association

John T. Klehr, Meteorologist/Systems Engineer, Singer Company

John Prodan, President, AV-CON



### INTRODUCTION

The Training and Simulation Committee in this year's Workshop has been very active. We have had excellent discussion with the floating committees as well as among ourselves. Our expertise ranged from advanced civilian-military training to general aviation-corporate training. We've had viewpoints from simulator and research experts as well as classroom academicians. I would like to thank each member of the committee for a job well done.

### GENERAL AVIATION

The study of meteorology for general aviation students is, in our opinion, inadequate for today's environment. Although ground and flight schools with sufficient information in the meteorology area are available, they are not currently required for pilot certification. Written tests for pilots, as required by the FAA, does not place enough emphasis on basic knowledge of weather phenomena and weather hazards. Publications available to the general aviation pilot on the subject of meteorology are not updated at a pace to keep up with the increasing knowledge being obtained in the area of weather phenomena. Our committee strongly feels that until requirements are mandated to insure that an adequate knowledge of meteorology and, in particular, weather hazards, are attained, we can continue to expect the general aviation pilot to "learn by doing". One suggestion to insure that each candidate for a pilot certificate understands the basics of meteorology and severe weather is the sectionalization of the FAA written exams. A pilot who then fails any

portion of the meteorology section of the exam should be required to retake that portion of the exam before being permitted to take his flight check for a particular certificate. A review of weather should also be included on a recurrent basis, such as in the biennial flight review.

Flight simulation for general aviation pilots has not progressed to the state of the art that is possible with today's technology. Simulators capable of demonstrating wind shears, turbulence, low visibility, icing...would be of great value to the general aviation community; but, we understand that it would be cost prohibitive.

Another important area in the training of pilots deals with the human factors. It appears that it is both practical and highly desirable that development of weather-related decision making should play a major part in the early training of pilots. Although the VFR pilot can't be trained for all weather conditions, early training can be planned to develop the pilot attitude of a thorough respect for weather.

Previous workshops have dealt with the human factors area in detail, and we recommend the implementation of their ideas. We challenge the FAA to explore regulatory changes; the aviation education community to supply curriculum development; and the simulator manufacturers to develop a generic general aviation aircraft simulator for in-flight weather training.

## CORPORATE AVIATION

As with the general aviation pilot, the requirements for a good working knowledge of weather is missing in our present certification process. Many corporations have well-established ground schools and recurrent programs; however, many do not. Corporate simulators are available which have full motion and visual systems; however, training syllabi do not, necessarily, include training in severe weather flying. Primary emphasis is based on aircraft systems, procedures and aircraft control. Simulators are believed to be the best way to teach crew coordination along with normal and abnormal aircraft operational procedures. The total pilot learning concept is desirable...not just the teaching of how to perform a certain maneuver. The thorough study of meteorology in ground school classes cannot be overemphasized. Films, such as those being produced as a result of the JAWS Program, along with qualified ground instructors are absolutely necessary to teach, learn and/or review the basics of meteorology.

## CARGO AIRLINES

Cargo carriers, which make use of simulators for training, are in dire need of accurate models for severe weather training. Some data is simply not available. Simulators are not necessarily programmed to adequately demonstrate the wind shear models and the question arises as to whether or not simulators are implemented to properly reflect wind shear. However, even with these questions, we feel that training should be given in wind shear recognition in order to educate the pilot. Icing and heavy rain are in the same category. Once data is available, it should be validated before implementation in simulators. Older simulators in the corporate market also need to be updated in order to begin effective training in weather flying. Advanced simulation training under FAR 121 Appendix H may be an incentive for updating some of these older simulators. We endorse the JAWS data program and any other program that would develop a more realistic, accurate, high-resolution data base for wind shear and the effect of heavy rain and icing for both crew training simulators and engineering simulators. At the same time, weather radar data and visual scene data should be developed and coordinated as a total package representation of the cockpit world.

## PASSENGER AIRLINES

Priorities of simulator updates for passenger airlines are wind shear, heavy rain, clear air turbulence, lightning, icing, frost, snow conditions, fog, low visibility and ozone/acid rain.

The incorporation of a line-oriented flight training program can best be utilized in the training of weather hazards for the airline pilot. The required six-months checks in conjunction with FAR 121 Appendix F do not provide a good avenue for this training. The requirements set forth in Appendix F are a "jump-through-the-hoop" type requirement, i.e., perform a particular maneuver and move to the next one. We feel that significant meteorology training for airline operation is important and that it should be done in a training concept, not as a required check flight. The wind shear model concern was also expressed, as it was in the cargo simulation training area. Heavy rain was also a concern because we do not have exact models of this weather phenomena and are not sure of the penalties encountered with aircraft performance.

## MILITARY AVIATION

Little emphasis is placed on adverse weather training in the military. The future looks good for computer generated images of weather displays and, in some cases, orders for such systems have already been placed by the military. Good academic training is present in the military environment. Classroom instruction is of high quality and the emphasis on classroom instruction is commendable. An area of concern to our committee was the lack of information distributed to the civilian community pertaining to military aircraft accidents and incidents. Many of the accidents that would help the civilian community as far as analyzing weather-related accidents is simply not available to the civilian aviator.

In conclusion, simulation training in conjunction with professional ground training in meteorology is a must. Weather models must be realistic as soon as research data becomes available.

We would like to thank the UTSI for the invitation to come to this workshop and a special thanks to the National Weather Service for the wonderful weather that they have provided while we were here. Again, a personal thanks to each member on our committee for their efforts.

## **SUMMARY REPORT: Communications Facilities Committee**

**Members:** Frank E. Van Demark, Chairman, Engineering/Management Consultant  
James Banks, ATC & Airspace Consultant, Scott AFB & ATCA  
Lt. Col. Ron Brown, Chief Staff Meteorologist, Wright Patterson AFB  
C. L. Chandler, Weather Manager, Delta Airlines  
Steven Cohen, Senior Staff Engineer, Martin Marietta Aerospace  
Steven Henderson, Meteorologist, CWSU Atlanta ARTCC  
Jack Hinkelman, PROFS Program Office, NOAA/ERL  
Fred Hochreiter, Chief, Data Acquisition Division, NWS  
Sidney Koslow, Associate Technical Director, Mitre Corporation  
Lt. Col. Cam Tidwell, Deputy Program Director, NEXRAD/DOD  
Terrell Wilson, Planning Specialist, Air Traffic Service, FAA  
David Winer, Manager, Energy Division, Office of Environment and Energy, FAA



### **INTRODUCTION**

This summary report addresses specific issues which arose during discussion with each of the user committees. The issues are listed under user committee titles and a summary of the discussion with recommended action and responsible agencies is presented.

### **I. CORPORATION**

#### **A. ISSUE**

Need direct access to the FAA aviation weather data base used by FAA FSS personnel to brief pilots.

#### **DISCUSSION**

Reviewed FAA FSS Automation Program which includes Pilot Direct Access via computer terminal (privately owned from home or office or owned by Fixed Based Operator and used by pilots) and by phone into the Voice Response System as is now operational in Washington, DC, and Columbus, Ohio. Reviewed other aviation weather programs, e.g., improved VOR broadcasts (State of Florida test) and aviation weather radar broadcast via VOR to cockpit printer.

### **RECOMMENDATION**

Seek means to accelerate programs.

### **ACTION**

FAA

#### **B. ISSUE**

Closing and Part-Timing of FAA facilities will cause loss of aviation weather observations.

### **DISCUSSION**

FAA is committed to continue aviation weather observations where part-timing or closure is planned. Weather observations will be contracted out, satisfied by FAA's automatic weather observations system or assumed by NWS.

### **ACTION**

FAA, NWS, Airport Sponsor

#### **C. ISSUE**

Aviation weather observations are not available for all airports having Instrument Approach Procedure.

## DISCUSSION

FAA program for AWOS will cover a total of 900 airports. NWS may cover some others. User and Airport Sponsor can supplement FAA/NWS plans, i.e., Sponsor purchased AWOS as done by the State of Virginia

### D. ISSUE

Professional quality of aviation weather briefing by FSS specialists varies.

## DISCUSSION

FAA regions (Air Traffic) conduct professionalism activities programs specifically directed to the problem. Also FSS Automation, training of FSS Specialists on use of automation and new CRT displays will use standard formats for aviation weather briefings. Through automation, software will be assisted in calling up aviation weather and Aero. information related to the pilots stated need.

## ACTION

FAA - Specialist Training  
User - Constructive interaction with  
FAA facilities

### E. ISSUE

Need aviation weather during en route flight. Suggested use of satellite communications.

## DISCUSSION

FAA programs include:

1. EFAS voice (via radio briefings)
2. Plan for weather radar digital data transmission via VOR voice channel.
3. Data Link up-linking of aviation weather products.
4. Request/reply by pilots via data link potential.
5. Satellite usage is not in current plan.

## ACTION

User/FAA technical interchange is continually needed.

### F. ISSUE

Icing in general is a problem i.e., reports by pilots need standards and reporting categories to gain more use of collected data. Icing problems predicted by FAA, NWS or others are too generalized, i.e., icing problem to one aircraft is not a problem to another aircraft.

## DISCUSSION

The total icing problem needs to be addressed by the Users/FAA/NWS to define terminology standards for reporting icing conditions, to develop aircraft instrumentation for automati-

cally report icing and to structure FAA/NWS icing reports to provide the information for pilot determinations of icing potential based on the type of aircraft flown.

## ACTION

User/FAA/NWS technical interchange directed to Aviation Safety.

## II. CARGO

### A. ISSUE

Similar to item I, Corporate Issues B and C. FAA personnel that previously read aviation weather observations for ATC Tower are no longer available; therefore, no aviation weather observations for that airport. Cargo user has volunteered to read tower instrumentation but could not get FAA approval.

## DISCUSSION

All users of an airport in this situation should get with airport sponsor to develop a user/sponsor requirement. The sponsor can obtain permission from FAA. FAA cannot deal directly with individual users.

## ACTION

User/Sponsor develop requirements.  
Sponsor/FAA make agreement.

### B. ISSUE

Forecast is needed for a destination airport but user cannot get one.

## DISCUSSION

Cargo aircraft flight times are into airports at hours when FAA/NWS aviation weather observations are not being taken. Lack of current aviation weather observations precludes NWS forecast.

## ACTION

Users/FAA/NWS should review the AWOS program plans for long-term airport coverage. In the short term, specific locations should be brought to the attention of NWS to review and possibly change weather observer schedules. Sponsor should cover locations not covered by NWS/FAA plans.

### C. ISSUE

Sensing, forecasting and communications of severe weather are erratic, of questionable accuracy and communications vary dependant on manual relay of information and/or low-speed communication systems.

## DISCUSSION

There are many NWS/FAA programs directed to the total area: Sensing - NEXRAD, AWOS, and



Denver PROFS; Forecasts - PROFS, Centralized Forecasting at Kansas City and Automated Route Forecasting (ARF); Communications - NWS/AFOS, FAA/NADIN, FSAS, VRS, CWP/CWSU, Improved TWEB (Florida TWEB Test); DOD/AMEDS.

## **ACTION**

NWS/FAA/DOD proceed with approved and funded programs.

## **D. ISSUE**

Wind Shear advisories as generated by pilot reports or ground sensors are not constructed with standards for communicating assessed severity. This causes varying comprehension/reaction of pilots.

## **DISCUSSION**

The need for standards has been recognized. A joint Government/user group developed standards. These have been recommended for adoption of FAA and NWS.

## **ACTION**

NWS/FAA update operations handbooks and AIM.

## **E. ISSUE**

Wind shears during en route flight are not sensed except as pilots experience and communicate such events. This information is spotty and not of great value except to pilots in the immediate airspace.

## **DISCUSSION**

NEXRAD will provide a far more accurate picture of airspace severe weather problems. This data when combined with other large-scale data (satellite) and processed as at Denver PROFS, will greatly improve the ability to sense/forecast severe weather, including wind shear en route.

## **ACTION**

NWS/FAA/DOD proceed with approved and funded programs.

## **F. ISSUE**

Late night PIREPs are apparently lost in the system.

## **DISCUSSION**

FAA facility staffing of CWSU positions is from 6:00 A.M. or 7:00 A.M. to 10:00 P.M. ATC personnel (except FSS) receiving PIREPs do not have the CWSU meteorologist to relay them to. PIREPs facility operations vary as to personnel training and procedures for this instance (no CWSU staff to receive PIREPs).

## **ACTION**

NWS/FAA/CWSU staffing for 24-hour periods and automation of CWSU (FAA FY 84 budget).

## **III. PASSENGER**

### **A. ISSUE**

FAA and user day-to-day flow planning does conflict at times due to differences in the exchange data base used for making decisions regarding major hub weather conditions.

## **DISCUSSION**

User weather offices project daily operations restrictions from early morning inputs by personnel geographically distributed through their service area. FAA Central Flow Control Facility is dependent on weather projections from CWSU operations the previous night since CWSU start up in the A.M. and aviation weather observations in the A.M. lag the initial FAA/user daily flow control planning.

## **ACTION**

Users and FAA review C<sup>2</sup>F<sup>2</sup>/user coordination process and basis for agreement regards predicting weather conditions at major hubs and resultant flow restrictions. FAA/NWS review earlier start up of aviation weather observations and forecasts for major hubs. FAA start up CWSU operations earlier in the day (as with users) to provide more current input to C<sup>2</sup>F<sup>2</sup>.

### **B. ISSUE**

Wind shear experienced by and reported by pilots on approach is not consistently created with the seriousness warranted (pilot's view) nor communicated rapidly via the ATC system.

## **DISCUSSION**

There is no apparent ATC procedure that is enforced and/or routinely followed to handle pilot reports of wind shear. ALPA provided the Congress (letter of 8/27/82) with recommended standard terminology to report wind shear (W/S) in five different levels of severity.

## **ACTION**

Recommended actions were:

1. FAA - ATC establish emergency procedure requiring ATC personnel to relay W/S report to next pilot.
2. FAA/users - publish standard terminology for reporting W/S.
3. FAA - establish NEXRAD-like systems at major, selected airports.

4. NWS/FAA review and improve emergency reporting procedures for timely area distribution of severe weather reports.

### C. ISSUE

Winds and temperature aloft are not timely or data is not accurate.

#### DISCUSSION

NWS winds aloft for user use at start of day are not current. NWS believes its Limited Area Five Mesh (LFM) model to be in use 12/1/82 will help resolve this problem.

#### ACTION

NWS implement LFM 12/1/82. Users monitor LFM results and advise NWS.

### D. ISSUE

"Preferred Routes" in use by FAA due to controller strike and the need to channel traffic into airspace that current FAA staffing can effectively manage causes uneconomical operations for the user, i.e., the most fuel-efficient routes are not used.

#### DISCUSSION

FAA appreciates the problems and is restructuring the ATC airspace sectorization for more effective use of personnel and to reduce need to use "Preferred Routes". These efforts receive user coordination through the NAR program.

#### ACTION

FAA - proceed with airspace normalization as rapidly as possible.

### E. ISSUE

Pilots are not, in general, supporters of the PIREP program, i.e., they are not aware of a systematic, conscientious FAA/NWS handling of PIREPs.

#### DISCUSSION

Pilot/ATC cooperation appears to vary - Denver Center/PROFS' cooperation and management attention to the value of timely weather communications, whatever the source, has demonstrated to pilots that a pilot/ATC cooperative system works. Several other centers were singled out for positive comments regarding the handling of PIREPs.

#### ACTION

FAA/user exchange operational experience at the facility level to forge a cooperative attitude and appreciation.

## IV. MILITARY

### A. ISSUE

Military pilot PIREPs given to FAA ATC do not get into reports system and exchanged with Military reporting system.

#### DISCUSSION

Military pilots, like commercial pilots (some airlines), are flight followed; PIREPs are reported back to their ground personnel and provided to other pilots in their system. The weak link appears to be the ATC/CWCU internal center communications. CWCU personnel can put PIREPs on Service A via Leased Service A automation systems as can FSS EFAS and in-flight positions. PIREPs so handled do get into the system and exchanged with the military.

#### ACTION

FAA - develop a system and procedures to facilitate ATC handling of PIREPs.

### B. ISSUE

Military pilots in peacetime flight and using UHF miss PIREPs transmitted by other airspace users who are on VHF.

#### DISCUSSION

Military pilots on UHF in the same airspace sector and under control of the same ATC personnel miss VHF voice communications. Civilian pilots hear communications on the ATC sector VHF radio.

#### ACTION

Military consider use of VHF in the NAS during peacetime.

### C. ISSUE

FAA/Military systems duplication, while driven by wartime needs, of themselves foster less than satisfactory weather service to all pilot groups (military and civilian).

#### DISCUSSION

Ground resources, people and systems, duplication cause dedication of a large military resource to military pilots. Integration of peacetime operations offer many avenues to improve aviation weather system. Joint programs, e.g., NEXRAD and JAWS offer common systems acquisition but are not directed to common systems operation.

#### ACTION

Military/FAA/users at national planning conferences such as this Workshop should openly explore integration of aviation weather systems operations.

## **V. GENERAL AVIATION**

### **A. ISSUE**

Access to aviation weather via FSS is not satisfactory - busy signal during poor weather conditions at the local FSS.

#### **DISCUSSION**

To overcome current workload/staffing problems that result in facility busy signals, 800 intrastate numbers have been put in operation by FAA to provide pilots access to alternate FSS's. AOPA has published a list of these numbers by state. FAA is also considering the expansion of its VRS service as in place in Washington and Columbus (ref. FAA's NAS Plan of December 1982).

#### **ACTION**

FAA highlight 800 number availability in AIM. AOPA highlight 800 number in their publication. FAA proceed with weather dissemination programs.

### **B. ISSUE**

EFAS is not in operation during daytime in some Northwest areas.

#### **DISCUSSION**

The circumstances could not be fully developed, i.e., coverage problem, part-time or staffing problem. FAA has not planned EFAS service cut backs.

#### **ACTION**

FAA to investigate.

### **C. ISSUE**

NWS forecast is not available for some areas of the country. (See response to Corporate Issue B and C; Cargo Issue A and B).

## SUMMARY REPORT: Operations/Airport Facilities Committee

Members: Thomas E. Greer, Chairman, Deputy Director of Airports, Salt Lake City Airport Authority

D. Neil Allen, Manager, Earth Station, Colorado State University

John Blasic, NWS Representative to FAA, NWS/FAA

John H. Enders, President, Flight Safety Foundation

Arthur L. Hansen, Consulting Engineer, Enterprise Electronics

Cathy J. Kessinger, Support Scientist, NCAR

James C. McLean, Jr., Meteorologist, NTSB

William Pickron, Manager, Sector Control, Federal Express

Russell Peterman, Senior Engineer, Radian Corporation

David A. Sankey, Manager, Meteorological Personnel, The Weather Channel

Andy D. Yates, Pilot, United Airlines



Andy Yates substituted for Tom Greer in delivering the Summary Report for the Operations/Airport Facilities Committee.

### INTRODUCTION

The committee on Operations/Airport Facilities was composed of representatives from many aspects of the aviation community including the airlines, the National Transportation Safety Board, research and development firms and other governmental agencies. It was the original intent to form both fixed and floating committees. The fixed committees represented that aspect of the industry that would generate data and disseminate information to the users of the aviation system. The floating committees would consist of representatives of the passenger airlines, cargo airlines, corporate aviation, general aviation and military aviation.

It was determined early on that the term "operations" and the information and data generated by operations at airport facilities would pertain strictly to that information pertinent to airport operations as opposed to the operations of the various other segments of the industry.

It was further determined that many of the meteorological topics which were to be discussed as

being generated at the airport, such as wind shear, turbulence, ozone, acid rain, etc., were not pertinent to airport operations. However, the topics were expanded to include runway conditions, braking action determinations and the dissemination of such information.

The topics which were discussed as they related to airport operations were:

1. Runway condition reporting during inclement weather, ice, snow and heavy rains;
2. Slant visual range information as it is determined and disseminated to the pilots of the various aircraft;
3. De-icing applied to the technique and procedures used to de-ice aircraft prior to take-off;
4. Fog and fog dispersal techniques were discussed, as well as what action and research is being done to deal with fog.

The remainder of the report will be broken down into how these various topics were discussed with each of the floating committees.

## RUNWAY CONDITIONS

In discussing runway conditions with the military floating committee, it was determined that there were no standards with regards to how to determine "runway clutter", how to measure it, and how to disperse it. The military committee reported that there was a method in existence which used a numbering system which is quite extensive and it related to each individual aircraft and airfield. It is determined that each of the various military fields around the country had a different way of measuring and disseminating runway conditions. Some operators simply use a pickup truck and drive it down the runway at a predetermined speed, slam on the brakes and report the braking action as good, fair, poor, nil, etc. Unfortunately, these reports do not have very much relevance to the various aircraft which would be landing on the runway surface. The general aviation group had very little to say regarding runway conditions, other than the fact that the general aviation community was usually relegated to a secondary role when runway conditions deteriorated during snow and ice situations. The passenger airlines, as well as the cargo airlines, felt very strongly that a criteria and a method were needed to determine accurately and relevantly exact existing runway conditions. They felt that work should continue for a number value that would be standard to all airports and could be applied to the various operating characteristics of aircraft using the airport. However, all operators felt that the best and most useful information that can be reported is to get the exact conditions which were existing on the runway surface as often as possible during inclement weather. This information would include the type of snow, whether it is dry snow, wet snow, slush, water, etc.; the percent of the runway which is covered, preferably at touch-down, mid-point and roll-out; and other conditions which might possibly affect the slipperiness or braking action of the runway, such as whether the runway had been plowed, broomed, sanded, treated with chemicals, etc.

## DE-ICING

The methodology, technique and standards used for de-icing varied widely among the different user groups. The military had standards which were established at each airfield depending on the command at the field. They felt that the standards needed to be established regarding the percent of glycol water mix, as well as the training for the ground crews in the de-icing procedure. Another big question was: Who bore the final responsibility of determining whether or not the de-icing has been effective?

It was generally agreed that the pilot-in-command is always ultimately responsible.

The use of ice-phobics (material which tended to prevent ice build-up on a surface) was also

discussed. The military recommended that continuing research be conducted by NASA in ice-phobics and other materials.

There was not much discussion regarding de-icing in the general aviation community or corporate aviation. Cargo aviation and passenger airlines concurred pretty much with the military position.

## FOG VISIBILITY SEEDING

The fog phenomenon was discussed with each of the user groups. The different types of fog were identified such as warm fog, cold fog, etc. All of the groups felt that while research needed to continue on dispersal methods for warm fog, cold fog, convection fog, etc., emphasis should be placed on improving the instrumentation in the aircraft itself.

Experimental devices were discussed such as the "magic window" being tested by Federal Express. This consists of an infrared camera located on board the aircraft which then projects through a computer enhancer a picture onto a heads-up display screen in front of the pilot. This picture would, in fact, give a very close facsimile of the runway which was not visible to the naked eye. It was felt by all parties that continuing an expedited research should be conducted by FAA, NASA and other groups in the development of reliable landing aids which would then be available to all the users.

Another situation, which was discussed extensively with the military, corporate and passenger airlines, was the use of striated paint markings for Category 2 runways with a porous friction coarse asphalt surface. It was pointed out that the large amount of paint which is required to be used on a Category 2 runway tends to freeze faster than the surface itself. The paint also tends to clog the draining feature of the porous friction surface, thus reducing its effectiveness. The use of a striated painting technique, where the paint markings are put down in six-inch stripes with six-inch voids between them, greatly reduces the amount of paint that fills the gaps and also enhances the ability of the runway to effectively drain water. The FAA has resisted the use of striated paint marking on Category 2 runways because, in their estimation, it reduced the visual acuity of the markings. It was the consensus of this committee that the FAA should review and amend its policy regarding the prohibition of striated markings on the Category 2 runways. It was further pointed out that during actual Category 2 weather conditions, the visual acuity of the painted surfaces is of minimal value to the flight crew because of the reduced visibility. The committee agree that the enhancement of the friction coefficient on the runway was much more important than the ability of the pilot to pick up the painted markings on the runway. The user committee members pointed out that most of the reference checks used during these conditions was instrumentation and runway lighting.



The general aviation committee felt that moving the local flight service stations to a computerized, centralized point would have a detrimental effect on their operations. They felt that the data needed to be readily available at most general aviation facilities. They also felt that they wanted AIP funds to be used to provide needed facilities at the various general aviation fields. They further felt that the system should be standardized so that as they traveled to the various airports, they could be assured of the availability of accurate weather information.

In discussing lightning and other atmospheric conditions, the corporate aviation group identified a concern that many of the fuel handlers were using nylon jackets, which have the tendency to create a static spark. The information should be readily available for dissemination to fuel handlers and fixed base operators in order to eliminate the possibility of this type of clothing being used by ground handling personnel.

## **WIND SHEAR**

Although the wind shear phenomenon was discussed, it was felt that the expertise available in the Operations/Airport Facilities Committee was not sufficient to address the problem in the detail necessary. However, several of the members felt that they would like to submit for the record an individual recommendation which follows:

The 1981 committee reported the re-occurring theme that current wind shear detection systems are not adequate. This issue is stressed in the 1981 summary which reminds us that the wind anemometer array has always been considered by the committees as an interim solution at best. The development of Doppler radar technology, while extremely important to the subject of

wind shears, is still years away from implementation. Also, the large cost of these radars will permit their use at only the largest facilities.

Thus, it is extremely important to implement testing of several other technologies which show promise for cost effective wind shear detection. One such technology is the Doppler Acoustic Sounder. Although a large-scale FAA test of the acoustic sounder as a wind shear detection system was carried out at Dulles Airport (see Beran, the committee made the following observations: These systems are now available off-the-shelf from several U. S. manufacturers and the same type equipment is installed currently in at least 17 airports in Europe. The Doppler Acoustic Sounder has evolved rapidly in the last few years as an accurate, low-cost remote wind sensing system which is capable of detecting wind shears at altitudes up to 500 meters and temperature effects of a downburst event up to 2000 meters. Thus, when installed near a glide slope, downburst events could be detected well before they reach the glide slope. Additionally, when installed on each end of an active runway, the Acoustic Sounder will provide protection for both in-bound and out-bound traffic. The very low-cost of these systems ( $\approx$  \$50,000) necessitates another close look at the cost/benefit ratio between this technology and other Doppler systems.

Specifically, the next two years will be spent analyzing data from the JAWS study which, unfortunately, did not include an acoustic system. Therefore, the FAA should commit funds as soon as possible for a small-scale test of a Doppler Acoustic Sounder System. This test should run for one calendar year and would best be carried out at Denver's Stapleton Airport since JAWS demonstrated a fairly large number of events at this location.

## SUMMARY REPORT: Satellite Facilities Committee

Members: James F. W. Purdom, Chairman, NOAA/NESDIS/RAMM, Colorado State University

August H. Auer, Jr., Professor, Department of Atmospheric Science, University of Wyoming

John L. Keller, Research Meteorologist, University of Dayton Research Institute

Vincent Oliver, Chief Meteorologist, Environmental Satellite Data, Inc.

John S. Theon, Acting Chief, Atmospheric Dynamics and Radiations Branch, NASA Headquarters

William W. Vaughan, Chief, Atmospheric Science Division, NASA/MSFC

Thomas H. VonderHaar, Professor and Head, Department of Atmospheric Science, Colorado State University

Roger B. Weldon, Meteorologist, Applications Laboratory, NOAA/NESS/DOC



## INTRODUCTION

When we met in our joint committees, it occurred to me that many people here have never seen a satellite picture. Figure 1 is an example that uses two 1 Km resolution GOES visible images to show both what a picture looks like and also to illustrate a forecast capability. In the area "B", there are wave clouds; in the area "A", there are cumulus clouds. This change in cloud type locates a mesoscale boundary. Along the Texas/Oklahoma border, at the very western edge of the picture, a frontal boundary is moving into the area. The question might be, "Where in Oklahoma will the strongest convective weather develop? Precisely, rather than over a large area." As it turns out, the strongest convection develops where the boundary between the waves and the streets and the frontal boundary interacted to trigger very strong thunderstorms that produced tornadoes and downbursts--specifically, at that point--not all along the front or all along the mesoscale boundary. The point is, there is a lot of information available today using satellite data that can help in aviation forecasting. Our committee felt that satellite data can be utilized for aviation applications a lot better than it is today. We found what appears to be a huge gap in technology available versus the information that's reaching the user community, as well as a gap in the user's knowledge of how

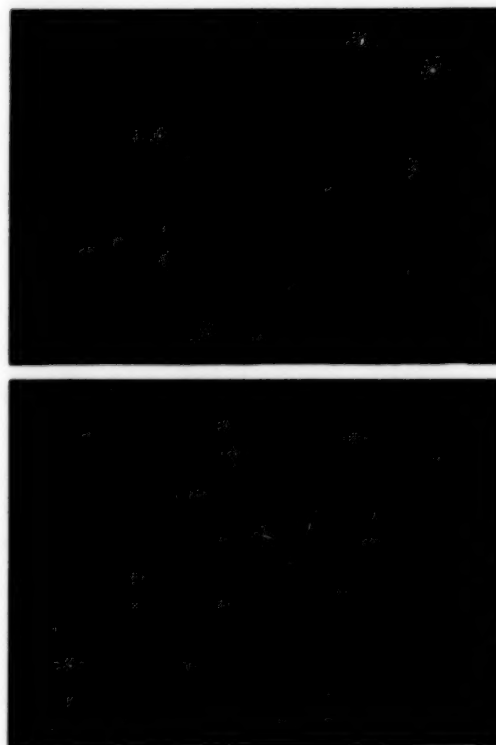


Figure 1. Example of Two 1 Km Resolution GOES Visible Images

to apply that information if it gets to him in the first place.

Furthermore, we found that most of the aviation weather problems that we discussed were in a nowcast time frame, i.e., in very large part 0 - 6 hours. What I will do is address what we found in the individual meetings with the different floating committees and then summarize. Most weather-related problems can be broken down into two broad areas: weather en route and weather at the terminal.

## **CARGO AND PASSENGER AVIATION**

1. Weather en route
  - a. Winds and temperature - Minimum Energy Routes using Interactive Techniques (MERIT), VAS, real time relay;
  - b. Thunderstorm development - Severe Weather Avoidance Program (SWAP), lightning;
  - c. Visibility - Dust, volcanic ash;
  - d. Severe CAT - Passenger/cargo comfort.
2. Weather at terminal
  - a. Thunderstorm - Microburst (wind shear, heavy rain);
  - b. JAWS.

For weather en route, there were similar needs with the cargo and passenger groups primarily for winds and temperature. This information was mainly for flight planning. This need for providing better wind and temperature information is one of the major goals of the MERIT program. To provide better information, there is a need for more research in the area of indirect sensing of winds and temperature using satellite data. Going along with this, there is continued need for development of our understanding of large-scale weather systems, especially those over the oceans in remote and data-scarce areas. This, understandably, will help us derive better wind field information from the frequent internal temperature sounding data that will eventually become available using GOES-VAS. Another area where wind information can be improved is to relay winds from aircraft en route using satellites; from this, you could have near-continuous updating of the winds for en route aircraft.

In the area of en route thunderstorm development, it was pointed out that when SWAPs are implemented, they have substantial impacts on air traffic routes regardless of whether thunderstorms develop or not. If a SWAP goes into effect, evidently aircraft cannot move as

freely from one place to another. Therefore, being able to forecast where thunderstorms will develop, as well as how they will evolve over the next hour or two, is extremely important. Lightning was also felt to be of importance and will become increasingly important as aircraft evolve more toward composite materials and fly-by-wire systems. In the area of visibility, en route weather problems are dust and volcanoes...things of that nature which satellites have been routinely detecting, and for which information is usable right now if it can get to the user community. Severe clear air turbulence was not considered as important as the topics listed above.

In the area of terminal weather, the hot and heavy thing right now is the microburst with its wind shear and heavy rain. Programs such as JAWS should have significant impact here. We must get a better understanding of what causes the downburst and microburst to occur. Combinations of rapid scan interval satellite data and three-minute interval imagery, with Doppler radar data should help in this area.

NOAA, NASA and FAA all have responsibilities in the above areas. MERIT and JAWS are already combined programs, with NSF being active in the JAWS effort. The development of a lightning sensor is clearly a NASA responsibility with NOAA involvement if this is to be done from spacecraft. Work at NASA indicates that a real time high resolution lightning sensor could be added to the GOES spacecraft at a nominal cost--this certainly needs further investigation. NOAA, NASA and NSF must give high priority to utilization of GOES-VAS multispectral imagery and dwell sounding data for aviation applications.

## **MILITARY AVIATION**

1. All weather, anywhere all the time
  - a. Must have reliable information
  - b. May not have ground-based observations
2. Weather at objective most important
  - a. Point specific (0 - 3 hours)
  - b. Varied mission - tactical to strategical
  - c. Nowcast intensive effort
  - d. Lightning - cannot detour
3. System design
  - a. Need for adequate data bases
  - b. Climatology of satellite data and applications

#### 4. Soundings from satellites

- a. TIROS-N, VAS
- b. Impact of soundings
- c. VAS development

The military requirements were, as you might expect, all weather anywhere, all the time. In-situ observations may not be reliable, i.e., many times they are not available at all... so, how do they get the information? In actuality, it turns out that the weather at the objective is very important. The weather information needs to be point specific for a three-hour or less time frame, and the mission may vary from paratroop drops to strategic operations. This is certainly a complex nowcast area: various types of weather can exist at different seasons of the year in different geographical areas.

It's not as simple as saying that thunderstorms are the most important. If you go to northern Europe at a certain time of year, fog and stratus become extremely important. Nowcast requirements vary greatly. As far as lightning in point specific weather, the military will probably design around that problem. At times, they have no choice but to fly into regions of lightning activity.

System design is one of the important military uses of weather information. It was pointed out that an inadequate climatology of satellite data existed to help that area.

Meteorology has moved into the era of the TIROS-N polar-orbiting satellite; and soundings from those satellites have had a positive impact on numerical weather prediction. There needs to be some type of updating of the status of atmospheric temperature sounding using satellite data. We now have the GOES-VAS satellite which has the capability of taking sounding data from geosynchronous altitudes at fairly rapid intervals. This capability holds tremendous promise for the short-range forecasting of convection and severe weather.

NEPERF and AFGL, along with civilian agencies, have responsibility in assuring needs are met. For improvement of nowcast ability, the military should have personnel assigned to the PROFS program. The military should also support the acquisition of a more complete satellite climatological data base along with efforts already underway in NOAA, NASA and NSF. Efforts at AFGL and NEPERF should focus on investigating, and supporting investigations of, phenomena important on a nowcast time frame such as thunderstorm produced arc cloud lines.

### GENERAL AVIATION

#### 1. Flight time frame

- a. Generally less than 3 hours

#### 2. Nowcast problems

- a. Thunderstorms
- b. Icing
- c. IFR conditions

#### 3. Access to information

- a. Flight watch - EFAS
- b. A. M. Weather
- c. Continuous weather information

For general aviation, most flights are of less than three hours. Two basic types of pilots are: the VFR and the IFR pilot. Their main problem is lack of access to meteorological information, with their primary problems coming from thunderstorms, ice and a VFR pilot getting into IFR conditions. There are certain areas where satellite data can help solve those problems. For the thunderstorm and the icing problems, there are ways through image analysis and interpretation to get a nowcast of where ice clouds are, or where thunderstorms will develop. For IFR conditions, using imagery, we can tell where it's overcast and how it's changing in time. We can see the tops of the clouds and tell their height, although we can't see their bases; however, that information can be surmised by combining other types of information with satellite data using interactive analysis systems.

A tool that should be utilized more is the remote data collection platform. Platforms can be designed to transmit local weather information back through the satellite to a terminal, thus providing users with more surface weather observations. The flight watch, EFAS, that has been talked about is the primary interface with the general aviation pilot once he's airborne. The EFAS personnel must have satellite imagery in animated form, along with the tools to use it and the most up-to-date weather information that is available. We felt that the EFAS people certainly need training to interpret all the data types that they have. We feel that, perhaps, they should be professional meteorologists, although many of these people, we realize, do have a broad background in weather. This is clearly an FAA responsibility.

Many pilots have a very hard time contacting the FSS and getting their pre-flight briefing from AM Weather. This program, we felt, needs to be expanded so that it is available on a more frequent basis. This could be done through some NOAA and FAA effort. Continuous weather information! One of the items that kept surfacing was the use of the AM Weather channel for pre-flight briefing of a pilot. Perhaps, the TV channel that exists now, perhaps a channel that would just carry satellite data--zooming in on different parts of the country--radar data might be carried too. It is clear



that some mechanism is certainly needed for continuous weather updating for pilots.

The pressing need in general aviation is, obviously, access to up-to-date information. This is clearly an FAA and NOAA problem. The information must be placed into the hands of the EFAS person who has direct contact with en route flights -- these people must have the tools necessary to interpret that information and the training required to interpret such information as animated satellite imagery. This is clearly an FAA responsibility, with some of the training responsibility resting with NOAA. The AM Weather program should be expanded, and a commercial television weather channel having up-to-date weather information that includes current animated satellite and radar data is needed. This is a NOAA, FAA and private sector responsibility.

## CORPORATE AVIATION

1. Flights 1 to 2 hours, long distances
2. Lack of terminal weather
  - a. Remote DCP
  - b. Nowcast
3. Optimum fuel consumption
4. Pre-flight briefing very important
  - a. AM Weather
  - b. Accurate 0 - 3 hour forecast of en route weather

Corporate aviation has many of the same one- to two-hour problems as general aviation; but their flights are over longer distances. It was our understanding that corporate pilots are so busy once they get into the cockpit that they don't have time for many updates en route. Furthermore, there is a serious lack of weather information for many of the terminal areas into which they fly. This points, again, to the need for remote data collection platforms and access to that information, as well as accurate nowcasting of ice, terminal ceiling and visibility and wind shear. Corporate aviation has the optimum fuel problem that the other airlines have and most of their information on winds and temperature comes from briefings in the pre-flight phase. Again, for them to operate successfully, this means a good accurate nowcast of weather en route and at the terminal.

The requirements and needs for corporate aviation have, in large part, been covered in those of previous users--that is, winds en route, nowcast and so forth--agencies with those responsibilities have been pointed out. Additionally, many corporate aviation groups

have their own forecast services--these people need up-to-date weather information and the tools and training to use that information. Accessibility to the information as well as basic training development is a NOAA responsibility, while getting the information, displaying the data and acquiring the training is the responsibility of the private sector.

## CONCLUSIONS

There are many areas where satellite data can be better used today to aid in aviation, and we mean today, at this very minute. Use of these data will require user access to the satellite information and user training in the use of that information. Many users of meteorological information are adequately trained in synoptic, large-scale meteorology--weather of importance to much of aviation is mesoscale or small-scale in nature. Satellite data in combination with radar and surface observations are our main tools for short-range forecasting of mesoscale phenomena--we must have adequate interpretation tools in the field for analysis of these data sets, as well as meteorologists that are trained to use them.

We found four major, broad areas that need continued emphasis in their development. All are being addressed to some extent by NOAA, NASA and the FAA through MERIT, PROFS and CSIS or other programs.

The major areas for continued development are shown in Table 1 and some of the technology that may be brought to bear on certain of these problems is shown in Table 2. While much of the responsibility for development and use of the technology lies within NOAA, NASA and FAA, there are certainly some major places where the military and NSF also have responsibility--these must be coordinated as much as is feasible.

Once a person has used satellite data, he will understand why it is a must in local weather forecasting. Local weather happens on scales between normal observations, except with satellite data. Routinely animated GOES satellite imagery is absolutely required for short-range weather forecasting, and that information must be a part of any training program. For flight watch and the flight service stations, there is a technology

Table 1. Major Areas for Continued Development

1. Winds en route
2. Nowcasting - Terminals and flight paths
3. Lightning detector on Geostationary Spacecraft
4. Global satellite climatological data base.



Table 2. Available Technology with Great Promise

1. Winds en route
  - a. VAS
  - b. Cloud Motion
  - c. Image Analysis
2. Nowcasting
  - a. Image Analysis
  - b. Rapid Scan Data Combinations
  - c. VAS Technology
  - d. DCPs

available--training, education and the technology are all needed. Finally, we should expand AM Weather and the TV weather channel to carry one of this up-to-date information since this is how so many pilots in general aviation and corporate aviation get their weather information.

These, basically, are the findings of our committee.

RESPONSE: Jack Hinkelman, PROFS

I want to second what Jim said about satellite inputs. They are very important to PROFS, and they are also very important because the CWSUs have GOES drops right now. I showed a viewgraph before. When we were evaluating products to send to the CWSU, it was primarily based on some 1981 information; and they had a problem with the GOES navigation. That has been corrected. There's no problem. It's a very important input.

## SUMMARY REPORT: Forecasting Facilities Committee

Members: Fred Ostby, Chairman, Director, NSSFC, NWS

Herbert I. Brody, Assistant Federal Coordinator, FAA, NOAA

Frederick H. Carr, Department of Meteorology, University of Oklahoma

Sepp J. Froeschl, AES CMD

Demos T. Kyrakis, Senior Research Specialist, R & D Associates

Robert G. Miller, Senior Scientist, NWS, Techniques Development Lab.

Robert Serafin, Director, Atmospheric Technology Division, NCAR

Joseph F. Sower, NEXRAD Deputy Program Manager, FAA

Jan Tissot Van Patot, Meteorologist/Instructor, Atmospheric Environment Service

Tommy W. Trimble, Regional Aviation Meteorologist, NWS

Paul S. Trotter, Meteorologist-In-Charge, CWSU, FATCC



### INTRODUCTION

I just wanted to say that our forecasting group, I think, really benefited from the interaction we had with the various user groups to find out more about what they needed.

### DISCUSSION

We solicited the five (5) different committees that came through and we've taken the liberty to lump some of these together; where there are exceptions, they will be noted. In the Passenger, Cargo and Military areas, there were several areas of common concern. One of the concerns involved communications. We found that internally these systems had very excellent communications: getting information within their own systems; but, externally, we had a number of problems. Of course, while not specifically a forecasting problem, but a communications problem, it has an impact on forecasting. For example, the system response problem: the terminal forecast goes bad; there is a time lag from the time forecasts are updated and back into the system. Also, there are problems in getting pilot reports shared through the system. The time frames of interest for most of these groups were in the shorter range...down around 3 - 6 hours; although for planning purposes, the

military were interested in 12-hour forecasts. All committees expressed interest in some kind of sliding forecast, where it is periodically and consistently updated so that you could then march out another six (6) or 3 - 6 hours from a new initial point. Interests in icing forecasts were not great among these groups, except perhaps the military, in which one type of aircraft, the C-5, did not have the kind of anti-icing equipment that others had. So, for the military, icing forecast was a problem.

Ceiling and visibility was more a problem for the military, again, for locations where forecasts are not generally prepared. All expressed an interest and concern about low-level wind shear. There was a concern about lack of observations, concerning mainly the military and the cargo people. The cargo people, particularly, were concerned as they had a lot of operations late at night and observation stations were shut down. Lightning was a large concern for the military, but to a lesser extent, for the other groups as well. The other groups recognized that lightning may be more of a problem later on as they acquired more sophisticated on-board electronic gear. Air turbulence was primarily a problem for the military and air refueling operations, although other groups acknowledged that clear air turbulence, if it became severe,

is certainly a factor as far as passenger comfort is concerned, as well as safety.

Severe weather was an important problem for all of these groups, particularly pertaining to real-time information on severity of weather and location of severe storms.

The next two groups were corporate aviation and general aviation. They complained about the lack of communications, or poor communications, in the system. They found it difficult to secure weather information that was updated in a timely fashion. Also, there was a problem in accessing forecast information...in particular, being able to access FSS briefers in any kind of timely fashion. Time periods of interest were primarily in the short range from 0 - 6 hours. For some planning purposes, there was interest in a forecast in excess of six (6) hours. Icing was a problem for many of the aircraft that had to operate at the flight levels in which icing tended to be prevalent. Ceiling and visibility was a problem, particularly for those stations that lacked observations. We have heard about this problem before. Low-level wind shear was acknowledged as a serious problem; and, as I mentioned before, particularly the lack of observations.

Lightning was not of much concern at this point. However, as future systems develop, there will be more concern in the future. Clear air turbulence was not expressed as a significant problem compared to other problems unless it became severe. Severe weather was indicated as important. All five (5) groups had little or no concern about the problems associated with ozone or acid rain. No one expressed a particular concern in these areas.

We tried to put together a quick and dirty matrix of some of these forecast parameters and some of the perceptions from the different groups as to what was important. We tried to make some assessment as to whether improvements were achievable in some of these areas; and, if so, how long it would take to make them. We also tried to make some statement about resources. Relative to forecasting winds aloft, the corporate and general aviation groups had it as a very high priority. Passenger and cargo groups listed it as a lesser priority. We felt that improvements in winds aloft forecasting were achievable in the near term. We know that NMC will be making model improvement and enhancement within the next year. With the advent of the next generation of computers, more frequent winds aloft forecasts and updates should be attainable. Icing was a very high priority item for the corporate and general aviation groups. We felt that this represented probably a long-term proposition as far as really being able to solve the icing problem from a forecast standpoint. There is more research that is needed, and new sensors to be developed. There is a lack of observations of icing at the present time.

1. Low-cloud and ceiling problem was believed to be one that could be tackled now and not at

a great cost. One of the primary hopes in that area of significant improvement was, for example, using the work that Bob Miller described in his impromptu session yesterday morning, the GEM Statistical approach, where a forecast for a terminal can be made at a fairly low cost and can be updated frequently as information becomes available.

Low-level wind shear, a high priority; however, it looks as if it's going to be quite a while before that problem is solved or amenable to solution. We can see some of the shorter benefits, such as John McCarthy mentioned last night. Particularly, in the area of education and awareness. As far as any kind of detailed forecasting of a low-level wind shear, that's going to take quite a bit of effort and it's going to be costly.

Lack of observations is a high priority for the military as well as for some of the corporate and general aviation people. We considered that a long-term effort at high cost would involve the advent of automated surface observations as they become available. Lightning forecasting was mainly a secondary priority, but still significant as far as the military is concerned. Here again, I think there is a need for new technology, better observation and detection, and ways for getting the information into the system and disseminated. Similarly, clear air turbulence (CAT) is another phenomenon that one cannot easily forecast because of its transitory nature and relatively small scale. Thus, forecasting CAT is not going to be a near-term, high-payoff proposition.

Severe weather is a major concern for all areas. There are improvements that are available in the short term. We have new technology, resulting as an off-shoot of the MCIDAS development, that we are now working with in Kansas City. We have our own stand-alone system called CSIS, which stands for Centralized Storm Information System. I think we are going to see improvements through these developments and technology, at moderate cost.

In conclusion, many of the things which are needed for aviation forecasting are things that deal with scales both in time and space that are quite a bit smaller than what we work with at the present time. There is a strong need for greater temporal and spatial resolution, both in forecast models and in observations. We think that NOAA should develop these through its research laboratories and that FAA, assisted by NASA, should establish observational data.

One of the common threads among our groups is the need for better education of the aviation community as far as meteorological problems are concerned. Developing and fostering a better understanding of meteorology, as well as better training for pilots in the area of meteorology, is needed. This probably falls into the arena of the FAA. For many of the things that need to be done, technology is available; however, there is a monetary need in order to develop them and get them on-line and operational.

## SUMMARY REPORT: General Aviation Committee

Members: Russell S. Lawton, Chairman, AOPA

Don Cornwall, Pilot, Delta Air Lines, ALPA

Norman L. Crabill, Aerospace Technologist, NASA/Langley Research Center

Kenneth M. Glover, Chief, Ground Based Remote Sensing Branch, Air Force Geophysics Laboratory

Jean T. Lee, Program Coordinator, NSSL

JoAnn Painter, President, JoWen Aviation

Robert J. Shaw, Aerospace Engineer, NASA/Lewis Research Center

Robert K. Sleeper, Aerospace Technologist, NASA/Langley Research Center



### INTRODUCTION

I'd like to give a quick overview of what the General Aviation Committee believes is important to the general aviation community without going into too much detail of what some of the other committee chairmen will cover. Reinforcement in a few areas couldn't hurt, though.

The other day in our briefings, we heard that weather-related accidents in general aviation account for four (4) out of every ten (10) fatal accidents and two (2) out of every ten (10) non-fatal accidents. When you hear those numbers, you know that weather plays a significant factor, but keep in mind that weather is cited as a factor whether it's a primary or secondary cause. Unfortunately, there is no area that you can single out and say if we could eradicate this problem, the problem of general aviation accidents would be solved. The diversity of the beast is such that it simply is not possible. The number one priority of the General Aviation Committee is getting better weather information to the pilot. It seems whenever we come to Tullahoma or other industry workshops, this recommendation always pops up. We hope if we continue to say it frequently enough and loudly enough, improvements will continue.

The general aviation pilot usually interfaces with the FAA Flight Service Station (FSS) when obtaining weather information. Our group does not have a high degree of confidence that the ability of the pilot to contact an FSS will increase with the planned automation and consolidation of FSS's around the country. The state-of-the-art allows better methods of obtaining weather information, and pilots should not rely solely on the FSS for obtaining this information.

### OBTAINING BETTER INFORMATION DURING PREFLIGHT PLANNING

Our group recommends that FAA make the weather products available so the user can tap the data base. This could be accomplished through the use of home computers, which are growing in numbers every day. Many people use them, and would not have to justify the purchase of one solely on the basis of obtaining weather information.

Several other types of self-briefing systems were tested by MITRE Corporation for FAA. The

voice response system (VRS) provides the pilot with a go/no go decision; or to, at least, obtain more data. Another system tested was the vu-set, which is a small CRT and keyboard that can be rented from the phone company. There was a lengthy discussion about presenting weather data on television as is presently on AM Weather and the Weather Channel. Our group believes all of these programs are useful in the planning stage, and a decision can be made to obtain more data, if necessary. A lot of weather information is available, but there seems to be a problem with government groups cooperating with each other. Private industry will have to pick up the ball in order to make the weather products more accessible.

## OBTAINING BETTER WEATHER INFORMATION IN-FLIGHT

The weather briefing process takes two forms: the pre-flight stage, and the in-flight stage. The most important information during the in-flight stage is the pilot report (PIREP). The PIREP is highly perishable information. It is useless if not disseminated quickly. There should be a simple mechanism for accepting and disseminating this information. One method suggested is the VOR voice channel. This is done during the summer months in the New York area when severe weather avoidance plans (SWAP) are in effect. A broadcast is made over the Phillipsburg and Coyle VORTAC's announcing the use of SWAP and the type of delays which should be expected. This device should be explored for disseminating pilot reports for a specific area.

We are encouraged to hear that lease service A will be installed in air route traffic control centers so that the center weather service unit (CWSU) can input PIREPS to the system. There is still the problem of getting the pilot reports, and getting that information passed from the controller to the CWSU.

A problem with en route flight advisory service (EFAS) was also discussed. Signal coverage for this service is not adequate in all areas, especially in remote locations where real-time weather information is a necessity.

## FORECASTING

There is a lack of credibility in the forecast, and our group believes this is a factor in aviation accidents. Many pilots do not have a high degree of confidence and simply do not believe the forecast. It was acknowledged by the forecasting people that this area could be improved. The two critical areas for planning are the long-range forecast (24 hours) and the 12-hour forecast. The 0-6 hour forecast is also important to assist in-flight decision making.

Another area of concern is the amended forecast. When it is necessary to amend a forecast, how bad is the weather going to be so I can make the right decisions? If the credibility of the forecast could be improved, hopefully, the pilot

will make the right decision on the ground. We would like the individual to make this decision on the ground, since this is a significant factor in weather-related accidents.

The forecast people indicate more real-time information would help them, especially towards improving the amended forecast.

## INCREASED WEATHER OBSERVATIONS

There is a fundamental division of pilots operating in the system; instrument-rated pilots and noninstrument-rated pilots. Both these groups have their share of accidents in proportion to their respective share of the pilot population. A member of the AOPA staff conducted a study of weather-related accidents and found that the noninstrument-rated pilot is most likely to have an accident during the en route phase of flight.

In those accidents reviewed, the accident occurred furthest from a weather observation site, which was not the destination airport. To restate the problem, these accidents occur closer to the destination than the observation point.

Our recommendation is to install automated weather observation equipment in those areas which lack real-time weather. It was mentioned that there are 900 automated observation sites planned for the near future. Our understanding of this program is that the actual number of weather observations won't increase. These automated sites will only replace human observers presently in existence. So it does not appear as if there will be an increase in the number of observations when the automated ones are in place.

There are approximately 2500 airports in the United States with approved instrument approach procedures, and less than 1000 of these airports have weather observations. We had always hoped the money for these much needed observations would be available from the trust fund, but it appears as if these monies will once again be impounded into the general fund. We hope this does not happen. Some of the money put into the coffers by the users should be returned for these type of aids.

## TRAINING

The areas our group believes are most important in training/simulation are: written materials and in-flight exposure to weather hazards.

Printed material provided by the FAA for pilots is woefully inadequate in certain areas. Icing is a good example. The official publication used by FAA to test pilots on icing contains only three (3) pages of copy on the subject. Certainly you will agree this area needs improvement.



There needs to be better training with respect to weather hazards. The inexperienced pilot should have the exposure to icing and thunderstorms as part of a judgment training program. The general aviation pilot is the first step in the training process for proper judgment training. Adequate training will prevent many problems further down the road as this pilot becomes a corporate or airline pilot.

With respect to meteorological knowledge, we should return to sectionalizing pilot written

exams so that it's no longer possible to pass one of these exams without sufficient weather knowledge. An individual should be required to pass the section of the exam on meteorology before continuing the certification process.

Finally, better training is needed for special types of equipment. Industry should make available formal training programs on the use of devices such as weather radar, de-icing/anti-icing equipment which a pilot does not ordinarily receive during basic training.

## **SUMMARY REPORT: Cargo Airlines Committee**

Members: Robert L. Giordano, Chairman, Federal Express Corporation

Keith W. Balcom, Staff Engineer, Air Line Pilots Association

John H. Bliss, Captain, Flying Tiger Line, Retired

Richard E. Cale, President, Environmental Research Applications, Inc.

Frenando Caracena, Physicist, NOAA/ERL/OWRM

Mark A. Dietenberger, Research Physicist, University of Dayton Research Institute

George H. Fichtl, Chief, Fluid Dynamics, NASA/MSFC

Ossi Korhonen, Research Meteorologist, Finnish Meteorological Institute

Byron B. Phillips, Manager, Research Aviation Facility, NCAR



The following topics represent issues addressed and summarize the discussion relative to those issues.

### **FORECASTING FACILITIES**

The basic domestic forecast requirement for aviation purposes is the 6-hour forecast.

There is a need for an examination of the parameters for timely update and revision of the original forecast.

Update or validate the original forecast at least every two hours, preferably each hour. Consideration should be given to a "running" forecast that is continuously good for a 6-hour period but renewed every two (2) hours or less, not just revised based on significant changes.

Tighten the parameters for revising a forecast based on the latest information, e.g., hourly or special observation, etc. Provide for a more direct and current feedback or interface between users and personnel producing the forecast.

Modify the use of terms such as "occasionally" and "intermittently" in the body of the forecast. That is useful information, however, it should be clearly identified as advisory in nature so as not to be used to determine the legality for filing to that location as a destination or alternate. Advisory information could be appended to the forecast message as a separate advisory, not a "remark".

### **USER PAYMENT FOR NWS PRODUCTS -NOT PRACTICAL**

NWS is not responsive to user's tailored requirements. We should not pay for a product that requires modification to satisfy our needs.

It is wasteful for NWS to generate a finished product and for a user or separate contractor to do the same work to satisfy user needs.

An alternative is for NWS to accumulate the raw data to be made more readily available to the private sector, allowing the users to contract for their desired services whether synopsis, wind forecasting, etc. Meanwhile, NWS can make their current products available to government agencies and assist them in preparing their unique products, i.e., FAA requirements for aviation weather; Department of Agriculture/Interior requirements for their weather products, etc.

Due to the reduction in weather observation capability resulting from recent tower closures and tower reduced operating hours and the reduction in Flight Service Stations, innovative methods are required to provide information for destination airports where meteorological data is not sufficient to satisfy current terminal forecast needs. There is a need for a "vicinity" forecast which is more detailed than current area forecasts and designed to provide better information than available from an observation several hours old.

## COMMUNICATIONS FACILITIES

Establish an effective, "no-hassle" method of handling PIREPs; assuring dissemination of PIREPs to those agencies requiring them, to include a prescribed level of detail.

The shortcomings created by closed or reduced hours FAA/NWS facilities must be overcome.

NWS and FAA should jointly act as a focal point for determination of user needs at a given airport in order to develop methods of acquisition/dissemination of weather data for that airport. NWS provide training and certification for a supplemental observation station.

Immediately begin utilization of closed/reduced hours FAA tower facilities for acquisition/dissemination of weather observations.

Assure the availability of weather observations at all public airports as a condition for provision of approach control service or for certification of instrument approach.

Provide for the dissemination of complete AWOS data. Criteria used by FAA and NWS should consider user needs, in addition to their own respective needs. No important observational data should be withheld, such as not reporting all cloud levels above a given altitude.

Develop a communications system, possibly a Data Link, to take advantage of real-time weather and wind information constantly available from en route aircraft (see Satellite section).

## TRAINING/SIMULATION FACILITIES

NOAA provide users with Flight Management-oriented material on the parameters for updating terminal forecasts; the AIM or an Advisory Circular could be used.

FAA must assure that adequate training is provided all users prior to implementation of Automated Flight Service Stations.

Recommend development of ground based and airborne wind shear detection systems for detection and avoidance of hazardous low-level wind shear.

Develop training procedures for:

- The use of ground speed, if available, on approaches as one possible means to cope with low-level wind shear;
- Optimizing performance of aircraft not equipped with ground speed or other wind shear detection devices;
- Use of new wind shear detection devices as they are developed.

Publish instructional data on low-level wind shear for pilots not using sophisticated flight simulators.

FAA take the lead and assure timely and adequate Research and Development results on low-level wind shear be made available for flight simulator application. The data would be used by the carrier, as coordinated with, and acceptable to, FAA Flight Standards, to enhance simulator programs.

## OPERATIONS/AIRPORT FACILITIES

Vigorously continue research and development on fog dispersal systems. Assure that such systems are fundable through the Trust Fund.

NASA vigorously pursue the establishment of standards for runway friction measurement and operational reporting of that data. Standards should be established for measurement, method of dissemination and computations of aircraft performance.

NASA/FAA should provide operational advisory information on the use of distance-to-go runway markers for performance checks/reference.

NASA/FAA develop procedures and equipment for the integration of ground speed indications and/or other airborne and ground based low-level wind shear detection devices.

Airport Management should bring together local interests (carriers, corporate aviation, FBOs, political) to determine the extent to which closed or reduced-hours tower facilities could be utilized for weather data acquisition/dissemination, and possibly airport advisories; seek FAA authorization for the use of those facilities and equipment where reduced hours of operation are in effect.

Weather satellite interests should solicit the attention of the aviation professional groups (ATA, IATA, ATCA, ALPA, NBAA, AOPA, etc.) in order to encourage their constituents to provide accurate and detailed PIREPs to be used in the correlation of satellite data; explain future benefits to be derived from such correlation to provide satellite capability to detect and/or forecast CAT and other aviation-related phenomena. Coordinate the use of communications satellites for the direct relay of weather satellite products to en route (especially oceanic) aircraft. Provide for communication satellite relay of synoptic weather data and observations to en route aircraft, especially oceanic. Encourage NASA and FAA to develop an automatic air satellite ground communication link to relay both weather information and aircraft position, altitude, and path for trans-oceanic flight. This development should rely on navigation data from GPS (Global Positioning System) to ensure accuracy necessary for improved air traffic control over oceanic areas.

## SUMMARY REPORT: Corporate Aviation Committee

Members: Leo Boyd, Chairman, Tennessee Eastman Company

Robert S. Bonner, Physicist, Army Atmospheric Sciences Laboratory

Warren Campbell, Aerospace Engineer, NASA/MSFC

Vernon W. Keller, Cloud Physicist, NASA/MSFC

Porter J. Perkins, Aerospace Engineer, ANALEX Corporation

Wayne Sand, Professor/Flight Facility Manager, Navy/University of Wyoming

Sheri S. Sankey, Consultant, Aero WX

Alan A. Woodfield, Head of General Aerodynamics Sect., Royal Aircraft Establishment



### INTRODUCTION

First, let me thank UTSI for inviting me here to represent business (corporate) aviation. It's been an enlightening experience for me to see how far this distinguished international group has gotten into some atmospheric science research in areas that really concern pilots in being able to maintain the highest level of safety in business/corporate aviation operations.

There is a purpose in corporations having business aircraft. These aircraft provide a transportation system to help gain more time for management. Business aircraft are among the few unique tools available which can gain real chunks of time for management versus those using mass transportation. In the business aircraft fleet, there are many single engine aircraft plus more than 12,000 piston twins, about 7,000 turbine-powered aircraft, and approximately 6,000 roto-craft, with most of the roto-craft being in the energy field (numbers rounded off). Of the airports that business aircraft operate into, 6,700 are public-use airports; 5,600 of them are paved; 4,600 of them are lighted and better than 2,000 have instrument approaches (numbers rounded off). There are approximately 430 control towers. Some of these are out of service temporarily and many of the remaining active towers close after 10:00 or 11:00 P.M., and open between 6:00 or 7:00 A.M. every day. Approximately 900 airports have weather observations; some of these are by certificated observers using unicom radios for transmitting weather information to pilots.

In considering general aviation versus business/corporate aviation statistics, we don't have a way of breaking out what is pleasure and what is business flying. All agriculture, business/corporate and general aviation aircraft together consume approximately 10 percent of the total aviation fuel plus transport approximately one-third (1/3) of all inter-city passengers. Commercial airlines transport most of the passengers on longer distance flights. Business aircraft operator companies contribute with their goods and services and associated business affiliations (example: auto manufacturers and their dealers) better than 50 percent of the Gross National Product.

Corporate priorities in its flight operations are: safety is first, second, third and foremost. Safety has to come first, or the rest of its services and conveniences are futile. Reliable transportation is next. It's better when you can expect to make your appointments. That's the reason management is providing aviation departments with better aircraft including better instrumentation in the cockpit. Many companies are now using contract training centers for their flight crews for six months proficiency training and currency checks just like the airline pilots get.

Economics is also a concern of business management in all of the afore-mentioned corporate aircraft operations. In any free-enterprise system, managers show the same concerns as managers in government agencies. There is just

not enough money to go around for everything for everyone; like you, we must prioritize our objectives.

High on our list is passenger convenience, flexibility and comfort and minimization of travel frustration factors; but these factors do not override the other factors whenever safety may be compromised. For safety, business aviation needs easier access to better weather information. The FAA re-emphasized to the business aviation committee during these meetings that until conversion to the new super flight service stations is complete, we are to be assured equal or better service as policy; but folks, it's getting worse in reality. We need relief now in easily acquiring real-time weather and notams information if safety is to be maintained and if we are to rely on the FAA/NWS's common system. In many airport weather stations, NWS personnel refuse to provide pilots with hard copy. We require more terminals with weather observations, automated or otherwise, and easy access to these.

Many of our flights are to remote areas which have poor to no weather information. As far back as President Nixon's time, there was a policy instituted to encourage building new industrial plants in remote areas as one means of dispersing the nation's industrial base and population for national defense. This is a unique national public benefit. Major dispersions of industry can help reduce the chance of enemy nuclear blackmail. It's also another means to help keep young people in rural areas by providing jobs there. However, if we can't get specific weather information, it is difficult to reliably dispatch aircraft into these places. It is relatively easy to travel between the metropolitan centers because they normally have excellent weather and navigation facilities.

We need better short-term forecasts for icing, particularly for the aircraft that's making an approach. If an aircraft ices up on approach and must make a go-around but cannot climb back up through the icing, folks, it then becomes a bad situation.

Accuracy of terminal ceiling and visibility measurement is still a big question. We find RVR is good; but, to date, do not believe its overall accuracy is good enough for go/no go decisions. We do make look-see approaches. But, as a confidence factor, it helps us in our efficiency, economics and planning if we find out early that the ceiling and visibility are too low for non-precision approaches and we cannot land; then why not divert at that time to an alternate airport, thereby saving time and money?

The committee was asked to establish priorities for icing, wind shear, the winds aloft accuracy, severe storms, etc. These factors are all important and we need all of this information when appropriate for safety and efficiency.

Businesses operate aircraft from small twins up to some 30 companies; who are operating two, three and four-engine Boeing-airlines-type aircraft. Most fly domestically and quite a few fly internationally. Business aircraft vary in operations from unpressurized in the lower levels up to 51,000 feet. More corporate aircraft are being certificated above 45,000 feet to be able to fly westbound above the stronger jet stream winds. From the business aircraft operator's standpoint, particularly for the heavier aircraft with the latest color radar equipment installed, the crews are getting pretty good information on severe storms. We normally use all the severe weather data available plus any other good weather information you providers have available, provided the information is timely and readily accessible. We must work responsibly with all available knowledge and information if we are to maintain safety, comfort and efficiency.

Judgment training is one thing that is in the early development stage (such as the Pilot Judgment Study contracted to Embry-Riddle University by FAA for research and development). When developed, it is hoped this training can get more people to use common sense and knowledge in a predictable, logical and rational manner. This type training, when available, can be extremely beneficial to aviation. We also need to institute state-of-the-art training to reduce the amount of a pilot's time needed for effective recurrency training. (A sage once said if you think training is expensive, try ignorance.) I'm convinced, it is more important than ever from listening to this group report on new developments in weather research and forecasting techniques, that formal classroom instruction must be reinstituted for basic updating of subject materials...not only for business aircraft crews and general aviation pilots, but for airline pilots, also. Classroom instruction in review of basic and new developments in aviation knowledge is essential and primary prior to making best use of advanced flight simulation for cost/operational effectiveness. We pilots as a group are permitting ourselves to drift. In the early days of contract school pilot recurrency training, basic subjects review was the first priority. From what you're telling us and from the things you have shown us, once you're a pilot, you don't necessarily remain a well-trained pilot. We can become forgetful in some areas if we do not receive refresher training in appropriate general subjects as cockpit management, FARs, ATC, meteorology, medical emergencies, etc., as well as advanced specific aircraft systems and flight simulation. As you know, among your own people and ours, motivation is not the same for each person; but we must do our best -- and we are all flying within the same system. I believe we must work together within the national system for improvement if it is to remain one of the world's best. Education with good guidelines for acceptable performance standards is, I believe, preferable to mandatory regulations. Mandatory regulations inhibit innovation.



I, personally, would like for the runway condition information to continue to be in inches; and for other conditions stated as breaking action is nil, poor, fair and good. Pilots talk this language. It will certainly be better when a new accurate digital system is developed; but we must all use the current system until a better system is developed. When everyone agrees to this new system and are trained in its use, then it can be widely implemented.

Are the runways clear? By this, I mean at night and/or during low visibility conditions when many towers are closed; and what about the 1,500 airports without towers which have instrument approaches to runways for day and night instrument conditions? Question for pilots - is there a car parked out there at night on the runway you intend to use; for example, unknown to you, is it also being used as a lover's lane? Has a damaged aircraft been left on the runway? I have also seen aircraft just left parked on a secondary runway. Have you? This is dangerous; and it can be just as bad as an aircraft flying into a downburst at low altitude, or most anything else. We're concerned about this. We don't know the answer. Federal Express' research on a fog-penetrating-type infrared heads-up display system may hold out hope.

We also have a real concern for lack of a system which provides pilots easy direct access to aviation weather. Ladies and gentlemen, we need hard copies of specific and professional quality aviation weather and NOTAM information. We need this to be able to review data and evaluate it in an ongoing basis while en route, and not just use a briefer's advice as to whether we should be able to fly or not. When you get into heavy all-weather operations (and business aircraft do operate Category 1 down to Category 3A by some

operators), you have to know a person well before you can take his/her advice on whether or not to go. We do need hard copies of weather data and a means to get it. All remote airports with lighted, paved runways with IFR approaches need automated weather-reporting equipment with airborne pilot access to this information.

We have a concern for getting more pilot reports into the system and disseminating these. Pilot reports into the ARTC - when the system is busy - seldom get spread around. People are only human.

## CONCLUSION

In review: These points covered are essentially our priorities with special emphasis on being able to get more information from remote broadcasting at the IFR airports where it is not staffed by FSS or NWS personnel. For most effective operations, we do need hard copies of weather/NOTAM information. We need recurrent training in all the subjects you're talking about here in this UTSI, NASA, FAA, NOAA Workshop if we are to continue to be well-trained professional pilots. Thank you.

### Questions from the Floor

QUESTION: Why do you need weather/NOTAM hard copy? Wouldn't television copy be just as good?

RESPONSE: We operators need it to assure effective flight planning and safe operations. For safety, the FAA requires hard copy of weather for all scheduled air carrier crews prior to take-off from each airport. There is no reasonable way to commit so much data to memory for long flights.

## SUMMARY REPORT: Military Aviation Committee

Members: Lt. Col. John D. Fox, Chairman, Director of Operations, USAF Airlift Center  
Capt. Norman E. Buss, Staff Meteorologist, Flight Dynamics Lab., USAF AFWL/WEF  
Harry W. Chambers, Acting Chief, Technical Integration Division, Directorate for Development and Qualification, U. S. Army Aviation Research and Development Command  
Col. Farid Cezar Chede, Brazilian Air Force, Retired  
Hugh J. Christian, Space Scientist, NASA/MSFC  
Maj. Gary A. DuBro, Chief, Atmospheric Electricity Hazards Group, AFWL/FIESL  
Maj. Edwin W. Jenkins, Assistant Chief, USAF - Air Weather Service/DNTS  
Weneth Painter, B-57B Project Manager, NASA/Dryden Flight Research Facility  
August M. Stasio, Pilot, United Airlines



First, I would like to thank Dr. Frost, UTSI and the sponsoring groups for inviting the military to participate in this workshop. I, as one of the military representatives, am in the strictest sense an operations type -- no technical background in the weather area -- strictly a consumer of weather information. This workshop has been a very enlightening experience as I've observed the interaction of the various groups and have become better informed concerning the major programs of participating organizations. I would also like to thank each of the distinguished members of our committee for his excellent work throughout the workshop.

### INTRODUCTION

This workshop has focused its efforts primarily on the needs of the users of aviation weather, both civilian and military. For that reason, it is important at the outset to understand that military and civilian aviation operations differ considerably even though there are some aspects that are similar.

The most common aspects are that both the civilians and military operate within the same airspace, along the same route structures and under the same "system" within the U. S., as well as many international areas. The large airlines, commuter airlines, and most corporate and general aviation aircraft generally depart from and land

at established airports within this system. When military aircraft operate from one airfield to another within the system, then our requirements for aviation weather are much the same as civilian requirements. However, most military missions do not operate in this manner.

Military missions most often depart home station with the primary destination or objective being something other than an established airfield...enemy targets to be bombed, air-refueling tracks for fighters and bombers, drop zones where we parachute in troops and equipment, or dirt landing strips where we offload men and supplies. Of course, during peacetime, these objectives are practice bombing and gunnery ranges, air-refueling training routes, and training drop zones and landing strips. When the mission is complete, the aircraft fly to a designated recovery base or back to home station.

During peacetime, the military constantly trains for its wartime mission; however, its wartime needs are vastly different from peacetime. Our military is committed to help defend countries located in all parts of the world and, consequently, during time of international crises, military objectives are often remote and distant points on the globe.

Military exercises are routinely conducted to test our capability to accomplish our mission.

Exercise BRIGHT STAR 82 provides an excellent example of the remote objective problem faced by our military today. This exercise involved the movement of a large number of airborne troops and their equipment nonstop from east coast bases to their objectives in the deserts of Egypt. The aircraft in this operation were inflight refueled twice en route to the airdrop northwest of Cairo. Some of the aircraft recovered in Europe while others returned directly to the U. S. In a more recent exercise, aircraft flew nonstop from east coast bases to Europe for an airdrop and returned.

These exercises illustrate in a real way the military's need for a capability to accurately observe the weather and produce valid forecasts on a worldwide basis. Each of these exercises required forecasts for multiple inflight refueling tracks over the Atlantic Ocean as well as the objective area and recovery bases.

Our military commitments may, in some cases, require short notice deployment of forces into areas of the world which have limited weather data available. These short-notice moves also limit our capability to move sophisticated mobile weather support systems into the area. Consequently the military needs improved capability to observe the weather in the areas of the world that are hostile toward the U. S. as well as those remote areas where we have limited or no observation capability. Civilian weather satellite systems offer potential coverage of many of these areas.

The committee concluded that there are two prime needs for military aviation and made recommendations for each.

Priority #1 Need is for a more complete and accurate worldwide data base for aviation meteorological parameters such as ceilings, visibility, winds and temperatures.

## **RECOMMENDATION**

The Air Force Geophysical Laboratory and Air Force Global Weather Central should continue development of weather satellite applications in conjunction with NOAA agencies. This should include improved wind and temperature sensing and the pursuit of the total use of civilian satellite data worldwide. They should also support development of remote automated surface observing systems such as the one currently under development by the U. S. Army.

Priority #2 Need is for improved objective area forecasts in the data sparse and data void areas. The objective areas include tactical and strategic targets, inflight refueling tracks, drop zones, etc., and the elements needed are clouds, ceiling, visibility, winds and severe weather.

## **RECOMMENDATION**

That Air Force and Navy research facilities in cooperation with other governmental agencies continue to develop and improve forecasting techniques and methodologies. Our requirements range from very short "go/no-go" forecasts (less than 6 hours) to long-range planning and decision assistance forecasts, normally 12 - 72 hours.

The committee found during interaction with the fixed committees several other areas of concern. These are discussed below in descending order of priority.

## **ATMOSPHERIC ELECTRICITY**

Lightning strikes have caused the loss of a number of military aircraft over the last few years. In just the last two years, two C-130 aircraft were lost when fuel tanks exploded as a result of lightning strikes. This weather hazard is of even greater concern as composite materials become more common in the manufacture of aircraft components and as digital flight control (fly-by-wire) systems become the norm in new aircraft.

## **RECOMMENDATIONS**

That the Air Force Flight Dynamics Laboratory, in conjunction with NASA and FAA, initiate a program to:

- (a) develop electromagnetic data for cloud-to-ground lightning from an airborne observation point; and
- (b) develop design guidelines and test procedures for fuel tank and electronic systems lightning protection.

## **FLIGHT SIMULATION**

The committee concluded that military pilots probably have less experience flying in severe weather than do airline or major corporate pilots. This is due at least in part to the fact that the military either curtails or suspends operations when severe weather is in the area, while the airlines try to maintain their schedules. For this reason, we believe it vitally important that the military have current state-of-the-art flight simulators which include weather effects to aircraft. The latest generation Air Force simulators are great improvements over the old in that some have computer generated visual systems and provide for excellent weather effects such as turbulence, ceilings and visibility. However, even these new systems are lacking in some areas such as wind shear.

## **RECOMMENDATION**

That the Air Force System Command, Aeronautical System Division continue to develop state-of-the-art simulators for military use. These systems should include visual systems and provisions for realistic models for weather effects such as wind shear, cross wind, turbulence, icing and heavy rain.

## **COMMUNICATIONS**

Two areas the committee thought needed additional emphasis were the processing of pilot reports (PIREPs) and the need for increased use of very high frequency (VHF) communications when in contact with an air route traffic control center (ARTCC).

The committee believed that PIREPs were rarely processed in a manner which makes the weather information available to other pilots in a timely manner. Although there seems to be a number of reasons for this, we believe this information is of such importance that efforts to improve the system should be undertaken.

## **RECOMMENDATION**

That the FAA and USAF Air Weather Service investigate ways of reducing the time required to process and disseminate PIREP weather information.

Not all military aircraft are equipped with VHF radios; but for those that are, increased use of VHF frequencies when talking with ARTCC could provide better weather cross-talk with civil aviation which uses VHF exclusively. If the military pilot prefers to not use VHF as the primary radio, then monitoring the Center VHF frequency could provide essentially the same information.

## **RECOMMENDATION**

That the Department of Defense and the FAA encourage the military to increase its use of VHF when operating within the air route traffic system.

## SUMMARY REPORT: Passenger Airlines Committee

Members: James F. Sullivan, Chairman, Weather Watch Manager, US Air  
David C. Burnham, Physicist, Transportation Systems Center, DOT  
Thomas H. Genz, Northwest Airlines, Inc.  
Kao-Huah Huang, Research Engineer, FMG Associates, Inc.  
James K. Luers, Senior Research Scientist, University of Dayton Research Institute  
John McCarthy, Staff Scientist, NCAR  
William W. Melvin, Chairman, Airworthiness and Performance Committee, ALPA  
H. Geoffrey Molloy, Manager, Flight Safety, Qantas Airways Ltd.  
Peter J. Super, Senior Engineer, Flight Controls, Boeing Aircraft Company



Tom Genz substituted for Jim Sullivan in delivering the Passenger Airlines Committee Summary Report.

### INTRODUCTION

The Committee on Passenger Airlines identified many areas of concern and addressed specific items, identified in each fixed committee discussion, in the following areas: wind shear, turbulence, fog and visibility, lightning, ice, frost and rain. We attempted to prioritize these items for our committee, but found that each time the discussions started, the problems related to wind shear and winds emerged as the most significant problem for our committee and dominated each committee session. I will try to summarize in point order what we concluded in discussion with each of the fixed committees.

In the Satellite Committee, it is our committee's opinion that more research in measuring winds aloft and temperatures is necessary. Satellite interpretation of lightning sensors now and in the future is necessary due to the needs of the new generation airplanes with composite and fly-by-wire concepts. The continued development in satellite analysis of large-scale weather systems is needed; the interpretation techniques should be available in a training program to allow the aviation community to understand these large-scale weather systems.

After meeting with the Forecasting Committee, it is our recommendation that the identification of meteorological conditions conducive to microbursts be pursued; and, when appropriate, an advisory or a watch issued. This is not to be considered a forecast or a warning and should be designed to raise the consciousness of the pilot and the controller. It is further recommended that the hourly forecast be changed to a 3/6/12/24-hour forecast with 3-hour updates. Also, a cost-effective means of soliciting en route pilot reports should be effected to improve forecasting. Research and development should continue towards the understanding of lightning fields to insure that this information is available by the time the new generation aircraft (composite and fly-by-wire) are put into service. There should be continued improvement of wind and temperatures aloft forecasting to improve flight planning abilities. This information should be available by 0300 local time, particularly for the airlines in their flight planning for the day.

The information that is available is late enough to cause some conflicts and it should be moved to an earlier time.



Communications Committee: It is recommended that the establishment of a program to increase the awareness of wind shear hazards be implemented. The program should establish responsibility, priority and authority to immediately transmit the hazardous condition to all concerned by tower and/or ATC personnel. Second point: the airline meteorological weather analysis should be included in flow control determinations and a general improvement in functional communications in this area would be most desirable.

Training and Simulation: Wind shear characteristics should be incorporated into training programs in general and should include two (2) items. First, the recognition of a severe situation; secondly, the understanding of aircraft performance in that condition. Second point: the industry should be aware that the capability of current simulations to reproduce realistic wind shear situations may be very limited. The wind shear data base used in many present simulator programs is seriously inadequate and potentially very misleading to crews being trained on those simulators. As a corollary to that, the results from the JAWS and similar programs should make data sets of wind and microbursts available in one year.

The last committee we met with was Airports and Operations. The first point is the importance of continued work on warm fog dispersal techniques. The second recommendation is that work should also continue toward improved instrument landing capabilities; including both the aircraft and the field. Third point: the National Weather Service Storm Detection (SD) Thunderstorm Reporting System should be retained in its present format, including Azimuth and Range (AZRAN), to insure maximum utilization. Vandalism of NAVAIDS and other vital equipment relating to flight operations should be addressed. It was noted that one of the low-level wind shear alert systems at New Orleans had been repeatedly put out of service prior to July as a result of vandalism. Another point is that it was felt by some members of the committee that a consortium operated car wash de-ice facility could have many advantages for the industry and should be examined. Finally, there are two points pertaining to operations. Research should be continued towards the resolution of the effects of heavy rain on the performance of aircraft; and, secondly, the exclusion of ozone from the interior of aircraft and the forecasting of ozone locations should receive continuing development by the affected airlines.

## CONCLUSION:

The committee is concerned that the capability of the NEXRAD Doppler technology to detect wind shear caused by downbursts, microbursts and gust front phenomena may not be fully utilized because of siting requirements necessary to satisfy all requirements of the multiple uses of NEXRAD. The unit cost of NEXRAD units will probably be too high to get appropriations for dedicated radars to monitor approach areas at every major airport. While the committee endorses the implementation of NEXRAD for en route and terminal meteorological information, we believe that dedicated Doppler radar should be acquired as soon as possible to provide limited volume coverage, rapid information update and the dissemination of wind and intense rain hazard information to both tower and cockpits in a simple, clear and concise format.

### Questions from the Floor

QUESTION: Alan Woodfield, Royal Aircraft Establishment, Bedford, England.

Just a sort of personal requirement, really, but it would be very helpful to me to get a little bit of a feel for how we might help a pilot in the cockpit to warn him earlier that he is getting into difficulties in wind shear. There's been no specific mention of that in any of the wordings come across so far. How would you see work in that area?

ANSWER: Do I understand your question...that you're asking if there has been a determination of the most effective way to communicate wind shear?

RESPONSE: Alan Woodfield

No. I'm asking whether, in fact, there is still a strong need to have wind shear information in the cockpit as opposed to the information you're stressing from the ground at the moment!

ANSWER: Yes. I don't think I have to elaborate on that, other than to say, yes. That is correct. It is very definite, very positive.

## SECTION VIII CONCLUDING REMARKS



## CLOSING REMARKS

Dennis Camp, NASA/MSFC:

I appreciate your attendance and participation in this, our Sixth Annual Workshop; and want you to be assured that were it not for each of you, the workshop would not be as successful as it has proven to be. I want to encourage you to direct any negative comments you may have to me or to any member of our Organization Committee, so that we may be able to take any affirmative action necessary to enhance the workshop's value to the aviation community. However, if you have positive comments, we ask that they be expressed to the members of your peer group, as well as to any others who may benefit from such comments. Thank you.

Peggy Evanich, NASA Headquarters:

Since Dick Tobiason is not here, I thought somebody needed to come up and say a few words for NASA. I want to thank Dennis for organizing this. I think you did a lot of hard work; and I want to thank all of you for being here and making it as successful, as it was. Like Dennis said, please pass the word on to any other interested people you think might be contributors to the workshop in the future. I'd also like to thank Walt Frost for what I think is imparting his own particular personality to the workshop, and making it such a success.

Walter Frost, UTSI:

Thank you, Peggy; that's kind of you. A concluding comment I'd like to make is that we need to get the information from this workshop distributed in a summarized form. We need to get it into the right places. If you have suggestions as how to best do that, please jot them down and send them to me. I know Frank Van DeMark has some good ideas and some good contacts in FAA and he's written some of these down here for me. What I'd like is to receive some suggestions from you on how to summarize the right information from the workshop for the right upper-level managers; and then, recommendations on how to get the summaries to them.

So, if you have ideas along that line, I would appreciate them. As Dennis said, if you think the workshop is doing the right thing, and many of you have already expressed to me that you do, in terms of getting a collective view of the users' requirements of the system, you might inform the proper upper-level management. It would certainly help us in the future in getting some of the right expertise. We sometimes have problems getting this at the workshop, because some groups of upper-level management do not understand exactly what it is that we're trying to do at the workshop. They think that it's strictly a meteorological workshop. In truth, it is; but we want much more than just the meteorology. There is the user and the weather information and how it's all handled. So, comments along those lines will be very helpful to us in keeping the program viable and effective.

We are debating, now, whether we will continue on an annual basis, or whether we'll go to an 18-month schedule basis. Dennis, who funds the program in the main, will have to make some decisions along those lines and we will welcome your inputs in making that decision.

Again, we've come to a close. I really appreciate your attendance. It is pretty much agreed upon by our staff and personnel throughout the Space Institute that this group is one of the very best in terms of personality and working cooperation. They always enjoy you people; we enjoy you. We know you're busy; and the fact that you take time to come here and give us your expertise and to help us put together a program like this is greatly appreciated. I really enjoy working with you. Thank you.

# **APPENDICES**

## APPENDIX A ACRONYMS

ACAR	ARINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM	BA	BRITISH AIRWAYS
ADI	ATTITUDE DISPLAY	BFG	B. F. GOODRICH
ADP	ADVANCED DEVELOPMENT PROGRAM	BSM	BACK-SCATTER METER
ADAP	AIRPORT DEVELOPMENT AID PROGRAM	CAT	CLEAR AIR TURBULENCE
AEH	ATMOSPHERIC ELECTRICITY HAZARDS	CDC	CONTROL DATA CORPORATION
AHP	ATMOSPHERIC ELECTRICITY HAZARDS PROTECTION	CG ATIS	COMPUTER GENERATED AUTOMATIC TERMINAL INFORMATION SERVICE
AFFDL	AIR FORCE FLIGHT DYNAMICS LABORATORY	CGI	COMPUTER GENERATED IMAGERY
AFGL	AIR FORCE GEOPHYSICAL LABORATORY	CH	CLOUD HEIGHT INDICATOR
AFOS	AUTOMATION OF FIELD OPERATIONS AND SERVICES	CNRC	CANADIAN NATIONAL RESEARCH COUNCIL
AFWAL	AIR FORCE WRIGHT PATTERSON AERONAUTICAL LABORATORIES	CONUS	CONTINENTAL UNITED STATES
AIM	AIRMEN'S INFORMATION MANUAL	COSPAR	COMMITTEE ON SPACE RESEARCH
AIRMET	AIRMAN'S METEOROLOGICAL INFORMATION	CRREL	COLD REGIONS AND ENGINEERING LABORATORY
ALPA	AIR LINE PILOTS ASSOCIATION	CRT	CATHODE RAY TUBE
ALWOS	AUTOMATIC LOW-COST WEATHER OBSERVING SYSTEM	CSIS	CENTRALIZED STORM INFORMATION SYSTEM
AMDAR	AIRCRAFT METEOROLOGICAL DATA RELAY	CSU	COLORADO STATE UNIVERSITY
AOA	AIRCRAFT OWNERS AND PILOTS ASSOCIATION	CW	CONTINUOUS WAVE
APU	AUXILIARY POWER UNIT	CWA	CENTER WEATHER ADVISORY
ARF	AVIATION ROUTE FORECAST	CWP	CENTER WEATHER PROCESSOR
ARINC	AERONAUTICAL RADIO INCORPORATED COMMUNICATIONS SYSTEM	CWSU	CENTER WEATHER SERVICE UNIT
ARTCC	AIR ROUTE TRAFFIC CONTROL CENTER	DABS	DISCRETE ADDRESS BEACON SYSTEM
ASD	AERONAUTICAL SYSTEMS DIVISION	DABS DL	DISCRETE ADDRESS BEACON SYSTEM DATA LINK
ASDAR	AIRCRAFT/SATELLITE DATA RELAY	DBV	DIAGONAL BREAKING VEHICLE
ASI	AIRSPEED INDICATOR	DC	DIRECT CURRENT
ATC	AIR TRAFFIC CONTROL	DMSP	DEFENSE METEOROLOGICAL SATELLITE PROGRAM
ATIS	AUTOMATIC TERMINAL INFORMATION SERVICE	DNA	DEFENSE NUCLEAR AGENCY
AVRADCOM	ARMY AVIATION R & D COMMAND	DOC	DEPARTMENT OF COMMERCE
AWOS	AUTOMATED WEATHER OBSERVATION SYSTEM	DOD	DEPARTMENT OF DEFENSE
AWP	AVIATION WEATHER PROCESSOR	DOE	DEPARTMENT OF ENERGY
AZRAN	AZMUTH AND RANGE	DOT	DEPARTMENT OF TRANSPORTATION
		DSD	DROP SIZE DISTRIBUTION
		DUAT	DIRECT USER ACCESS TERMINAL



DFAS	EN ROUTE FLIGHT ADVISORY SERVICE	JAWOS	JOINT AVIATION WEATHER OBSERVATION SYSTEM
EDF	EXPLORATORY DEVELOPMENT FACILITY	JAWS	JOINT AIRPORT WEATHER STUDIES
EPA	ENVIRONMENTAL PROTECTION AGENCY	JDOP	JOINT DOPPLER OPERATIONAL PROJECT
ERL	ENVIRONMENTAL RESEARCH LABORATORY	JFK	JOHN F. KENNEDY AIRPORT
ETABS	ELECTRONIC TABULATOR DISPLAY SYSTEM	JPL	JET PROPULSION LABORATORY
EWEDS	EN ROUTE WEATHER DISPLAY SYSTEM	JSPO	JOINT SYSTEMS PROGRAM OFFICE
FA	AREA FORECAST	LaRC	LANGLEY RESEARCH CENTER
FAA	FEDERAL AVIATION ADMINISTRATION	IATAS	LASER TRUE AIRSPEED SYSTEM
FAR	FEDERAL AVIATION REGULATION	L/D	LIFT-TO-DRAG
FBO	FIXED BASE OPERATION	LDV	LASER-DOPPLER VELOCIMETER
FL	FLIGHT LEVEL	LFM	LIMITED FINE MESH
FSDPS	FLIGHT SERVICE DATA PROCESSING SYSTEMS	LLWS	LOW-LEVEL WIND SHEAR
FSF	FLIGHT SAFETY FOUNDATION	LLWSAS	LOW-LEVEL WIND SHEAR ALERT SYSTEM
FSM	FORWARD-SCATTER METER	LPATS	LIGHTNING POSITION AND TRACKING SYSTEM
FSS	FLIGHT SERVICE STATION	LSA	LEASED SERVICE A
FT	TERMINAL FORECAST	LWC	LIQUID WATER CONTENT
GAMA	GENERAL AVIATION MANUFACTURER ASSOCIATION	MCIDAS	MAN-COMPUTER INTERACTIVE DATA
GASP	GLOBAL AIR SAMPLING PROGRAM	MDA	MINIMUM DECISION ALTITUDE
GE	GENERAL ELECTRIC	MERIT	MINIMUM ENERGY ROUTES USING INTERACTIVE TECHNIQUES
GEM	GENERALIZED EXPONENTIAL MARKOV	MLW	MAXIMUM LANDING WEIGHT
GOES	GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE	MSFC	MARSHALL SPACE FLIGHT CENTER
GPS	GLOBAL POSITIONING SYSTEM	MSL	MEAN SEA LEVEL
GWD	GLOBAL WEATHER DYNAMICS	MTOW	MAXIMUM TAKE-OFF WEIGHT
HIFT	HELICOPTER ICING FLIGHT TEST	MVD	MEAN VOLUME DIAMETERS
HISS	HELICOPTER ICING SPRAY SYSTEM	NACA	NATIONAL ADVISORY COMMITTEE ON AERONAUTICS
HIWAS	HAZARDOUS IN-FLIGHT ADVISORY SERVICE	NADIN	NATIONAL AIRSPACE DATA INTERCHANGE NETWORK
HUD	HEADS-UP-DISPLAY	NAS	NATIONAL AIRSPACE SYSTEM
IAS	INDICATED AIR SPEED	NAS	NAVAL AIR STATION
ICAO	INTERNATIONAL CIVIL AVIATION ORGANIZATION	NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
IFR	INSTRUMENT FLIGHT RULES	NAVAIDS	NAVIGATIONAL AIDS
ILS	INSTRUMENT LANDING SYSTEM	NB	NANOBARS
INS	INERTIAL NAVIGATION SYSTEM	NCAR	NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
IRT	ICING RESEARCH WIND TUNNEL		
IVRS	INTERIM VOICE RESPONSE SYSTEM		

NEXRAD	NEXT GENERATION WEATHER RADAR	SERI	SOLAR ENERGY RESEARCH INSTITUTE
NHC	NATIONAL HURRICANE CENTER	SIGMET	SIGNIFICANT METEOROLOGICAL ADVISORY
NMC	NATIONAL METEOROLOGICAL CENTER	SST	SUPERSONIC TRANSPORT
NOAA	NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION	SVR	SLANT VISUAL RANGE
NOTAM	NOTICE TO AIRMEN	SWAP	SEVERE WEATHER AVOIDANCE PLANS
NPRM	NOTICE OF PROPOSED RULE-MAKING	TAS	TRUE AIR SPEED
NRL	NAVAL RESEARCH LABORATORY	TCV	TERMINAL CONFIGURED VEHICLE
NSF	NATIONAL SCIENCE FOUNDATION	TIDS	TERMINAL INFORMATION DISPLAY SYSTEM
NSSFC	NATIONAL SEVERE STORMS FORECAST CENTER	TOMS	TOTAL OZONE MAPPING SPECTROMETER
NSSL	NATIONAL SEVERE STORMS LABORATORY	TRACON	TERMINAL RADAR APPROACH CONTROL FACILITY
NTSB	NATIONAL TRANSPORTATION SAFETY BOARD	TSC	TRANSPORTATION SYSTEMS CENTER
NWS	NATIONAL WEATHER SERVICE	TWEB	TRANSCRIBED WEATHER BROADCAST
OAT	OUTSIDE AIR TEMPERATURE	UDRI	UNIVERSITY OF DAYTON RESEARCH INSTITUTE
OWRM	OFFICE OF WEATHER RESEARCH AND MODIFICATION	UHF	ULTRAHIGH FREQUENCY
PATWAS	PILOT AUTOMATIC TELEPHONE WEATHER ANSWERING SERVICE	UK	UNITED KINGDOM
PDP	PROGRAM DEVELOPMENT PLAN	USAF	UNITED STATES AIR FORCE
PIREP	PILOT REPORT	UTSI	UNIVERSITY OF TENNESSEE SPACE INSTITUTE
PIRM	PRESSURE ICF RATE METER	UWS	UNITED WEATHER SERVICE
PMS	PARTICLE MEASURING SYSTEMS	VAS	VISSR ATMOSPHERIC SOUNDER
PROFS	PROTOTYPE REGIONAL OBSERVATION AND FORECAST SYSTEM	VFR	VISUAL FLIGHT RULES
PSBT	PILOT SELF-BRIEFING TERMINAL	VHF	VERY HIGH FREQUENCY
PVD	PLAN VIEW DISPLAY	VISSR	VISIBLE AND INFRARED SPIN SCAN RADIOMETER
RAE	ROYAL AIRCRAFT ESTABLISHMENT	VMC	VISUAL METEOROLOGICAL CONDITIONS
R&D	RESEARCH AND DEVELOPMENT	VOR	VHF OMNIDIRECTIONAL RADIO RANGE
RE&D	RESEARCH, ENGINEERING & DEVELOPMENT	VRS	VOICE RESPONSE SYSTEM
R&T	RESEARCH AND TECHNOLOGY	VS/ERI	VERTICAL SPEED/ENERGY RATE INDICATOR
RRWDS	RADAR REMOTE WEATHER DISPLAY SYSTEM	VSI	VERTICAL SPEED INDICATOR
RSRE	ROYAL SIGNALS & RADAR ESTABLISHMENT	VS/ERI	VERTICAL SPEED/ENERGY RATE INDICATOR
RVR	RUNWAY VISUAL RANGE	WAVE	WIND, ALTIMETER, AND VOICE EQUIPMENT
SAR	SYNTHETIC APERTURE RADAR	WBRR	WEATHER BUREAU REMOTE RADAR
SD	STORM DETECTION	WFC	WALLOPS FLIGHT CENTER
		WMO	WORLD METEOROLOGICAL ORGANIZATION

WPAFB WRIGHT PATTERSON AIR FORCE BASE  
WPL WAVE PROPAGATION LABORATORY  
WSFO WEATHER SERVICE FORECAST OFFICE

WSO WEATHER SERVICE OFFICE  
WSI WEATHER SERVICE INTERNATIONAL

# APPENDIX B

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